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FIG. 47.

FIG. 48.

FIG. 45.

FIG. 52.

FIG. 53.

FIG. 51.

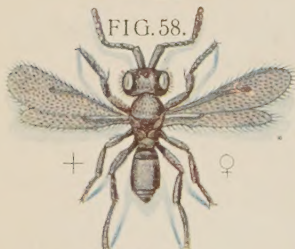FIG. 56.

FIG. 59.

FIG. 58.

FIG. 46.

FIG. 50.

FIG. 54.

FIG. 49.

FIG. 55.

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$\times 3$
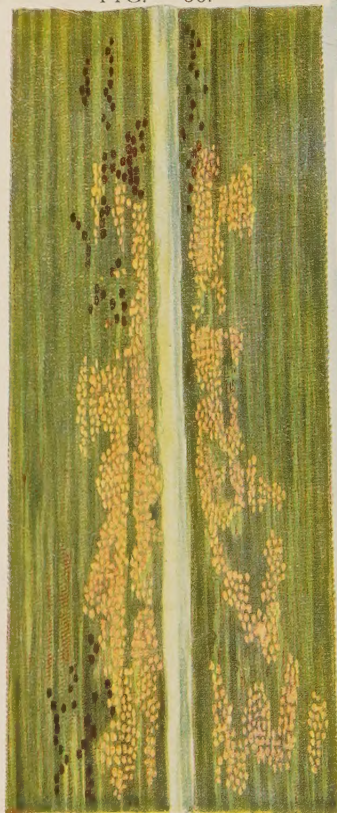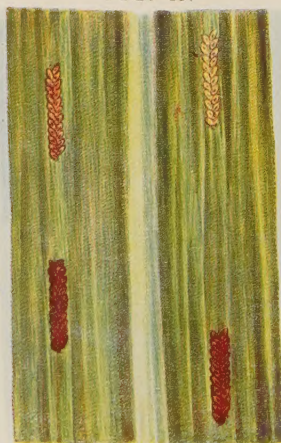
CANE SUGAR:

A TEXT-BOOK ON THE AGRICULTURE OF THE SUGAR CANE,

THE MANUFACTURE OF CANE SUGAR, AND THE

ANALYSIS OF SUGAR HOUSE PRODUCTS;

TOGETHER WITH

A CHAPTER ON THE FERMENTATION OF MOLASSES.

BY

NOEL DEERR,

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AUTHOR OF "SUGAR AND THE SUGAR CANE."

PREFACE.

THE absence of any recent English literature dealing with the sugar cane, which prompted me to compile " *Sugar and the Sugar Cane,*" can no longer be offered as a reason for the production of an extended textbook on cane sugar.

During the last decade the treatises of Geerligs, and of Jones and Scard, which specialize on cane sugar manufacture, have appeared; the detailed work of Ware on beet sugar manufacture contains much that is equally applicable to the sister industry; new editions also have been produced of Spencer's Handbooks, and of Newlands' Text-book. With so detailed a library available reasonable doubt may be felt as to the advisability of offering to the sugar public yet another compilation.

My experience of the cane sugar industry has been divided between the positions of chemist, of factory manager, of supervising chemist, and of sugar technologist in a large Experiment Station; and as in addition it has been spent in three sugar producing districts of widely variant character, it may possibly have fitted me to take a broad view of the salient points of the industry, and so to select for detailed treatment its more important aspects. Access, also, to a well-stocked library has enabled me to compile and present information not accessible to others less favourably situated.

The advisability of a chemist devoting considerable space to the botany, agriculture and pathology of the cane may be questioned. I, however, found it impossible to live on plantations without taking a keen interest in, and attempting to obtain something more than a smattering of, all phases of the production of cane sugar. I feel, then, that some account of these matters may serve to fill a lacuna in English technical literature.

It was only after mature consideration that I decided to let the chapter on 'Pests and Diseases' appear in its present form; the entomologist and the plant pathologist will be unlikely to refer to it for information. The account there given may serve, however, to stimulate interest in these destructive agencies, and in the means for their control, particularly in that known as the 'natural method,' which has been developed with such striking success in the Hawaiian islands by Koebele, Craw, Perkins, and their associates.

In selecting from the material at hand for use in this compilation, I have used much that is academic, as opposed to that of practical interest; although this selection may cause the compilation to appear too 'theoretical,' yet this reasoning has not made me depart from my ideal of inserting what I thought ought to appear, rather than what other people might think 'practical.'

In writing of matters which I can only hope to touch on as an amateur, there is danger of serious error. I have been fortunate, then, in the opportunity of having the earlier portion of my manuscript read by friends and colleagues, Mr. C. F. Eckart, Dr. R. C. L. Perkins, Mr. L. Lewton-Brain, and Dr. H. L. Lyon; but of course the whole responsibility for the matter therein contained rests with me. Those parts dealing with analysis were read over by Mr. S. S. Peck and Dr. R. S. Norris, to both of whom I am indebted for several suggestions.

To Mr. W. R. R. Potter and Mr. J. H. Wale I am indebted for the originals of many illustrations, including those of the coloured plates of the Salangore and the Purple Bamboo Canes, and of the coloured illustrations of insect pests, all of which are the work of Mr. Potter.

To the Experiment Station Committee of the Hawaiian Sugar Planters' Association my thanks are due for the loan of the blocks whence are printed Figs. 2-8, 63, 69, 70, 72-76, 82, 83, 105, 126, 188-190; those drawings illustrative of the anatomy of the cane were prepared under the direction of Dr. N. A. Cobb, and admittedly form a series remarkable as an exhibit both of technical skill and artistic merit.

Messrs. Baird & Tatlock have supplied the blocks used in Figs. 237 and 246; Messrs. Peters that of Fig. 238; Messrs. J. & J. Fric that used in Fig. 239; Messrs. Watson, Laidlaw & Co. those used in Figs. 207 and 208 : Messrs. Pott, Cassels & Williamson those used in Figs. 204, 206, and 209; Messrs. Bullivant & Co. that in Fig. 93; Messrs. Zeiss that in Fig. 262; Mr. T. L. Patterson that of Fig. 212; Messrs. Holden & Brooke that of Fig. 270 ; and the Richardson Scale Co. that of Fig. 269. Mr. J. B. Syme has supplied me with the originals whence Figs. 42, 88 and 98 were prepared.

It will be seen that I have quoted largely from the published works of Geerligs, of Went, of Kobus, of Harrison, of Eckart, and of Stubbs, to mention only a few of my sources of information. No work on any subject could pretend to completeness which failed to avail itself liberally of the results of the leading investigators.

I have departed from ordinary text-book conventionalism in inserting some notes in the Appendix, amplifying certain points in the text. Owing to my distance from my printers I received only a 'paged-out proof,' and it would have been possible only at some considerable inconvenience to have then made lengthy alterations in the body of the text.

My thanks are due to Mr. Norman Rodger for the trouble he has taken in seeing my manuscript through the press.

<div align="right">NOËL DEERR.</div>

Honolulu,
   November, 1910.

THE LITERATURE OF THE CANE.

The development of the scientific study of the cane only dates back a generation; this must be attributed to its decentralized position, and to the confinement of its growth to districts remote from the older centres of civilization; nevertheless, a voluminous and polyglot literature has now accumulated.

The earliest modernized treatise is that due to Wray, and published under the title of the *Practical Sugar Planter*, in 1848; this deals with practice in the West Indies and the Straits Settlements. Reynoso's *Ensayo sobre el cultivo de la caña de azucar* was published in 1865, and criticises Cuban practice. In the same year Icery's *Recherches sur le Jus de la Canne à Sucre*, the result of his Mauritian experiences, appeared. Twenty years later three other notable French treatises were issued: Delteil's *Le Canne à Sucre* (1884) gives a succinct account of the practices in Mauritius and Réunion; Basset's *Guide du Planteur des Cannes* (1889) is of the nature of a general treatise on agriculture specialized with regard to cane planting; and Bonâme's *Culture de la Canne à Sucre à Guadeloupe* (1888) contains the result of several years' experimental work, and is remarkable for a very complete detailed balance-sheet of the plant food material taken up by successive crops of cane.

Ten years later a German text book by Krüger, *Das Zuckerrohr und seine Kultur*, collated the earlier results of the Java 'Proef Stations,' and described in great detail Javanese practice. The conditions in Louisiana have been described by Stubbs in *Sugar Cane* (1897). The Egyptian industry has been discussed by Tiemann in *The Sugar Cane in Egypt* (1903); and finally Sedgwick in *Relating to the Sugar Industry in Peru* (1904) has given an account of the processes there followed.

Of the increasing amount of recorded experimental results appearing within the past twenty years in the English periodical journals, and especially in the *International Sugar Journal*, attention may be directed to the papers of Harrison, dealing especially with seedling canes, with manures, and with soils, and to the work which has been done by Watts and Bovell on kindred matter, and by Howard and Lewton-Brain on the pathology of the cane. In the English Orient a not unnoteworthy feature is the publication of papers on the sugar cane by several natives of India.

The United States are represented by records of work done at the Louisiana Experiment Station, and at that of the Hawaiian Sugar Planters' Association; and in this connection mention should be made of the work of C. A. Browne, dealing with manufacture and analysis, and of that in Hawaii concerned with agriculture and irrigation, initiated by Maxwell, and continued by Blouin and Eckart. A more recent phase of the Hawaiian work, and one referred to at

some length in the text, is the development of the 'natural' method of control of insect pests, under the direction of Koebele, Craw and Perkins.

In the French language the *Bulletin de l'Association des Chimistes de Sucrerie, &c.*, contains much valuable matter dealing with the sugar cane, to which H. Pellet has given many important contributions.

It is in Java, however, that the scientific study of the cane has reached its highest level. During the past twenty years there has come thence a series of papers, unsurpassed for academic interest and technical value by any similar series in any industry, either in Europe or America. The work of Geerligs on cane sugar manufacture, the pathological and physiological work of Went, Wakker, Krüger, van Breda de Haan and Kamerling, the cane breeding work of Kobus, Bouricius and Moquette, the engineering studies of Delfos, Bolk, and van Moll, the entomological researches of Zehntner and van Deventer, and the agricultural enquiries of Kramers and van Lookeren Campagne, make some knowledge of Dutch essential to the proper appreciation of the cane sugar industry.

In the pages immediately below is collected an imperfect list of books and journals dealing directly or indirectly with the cane sugar industry, with names of publishers where known.

AGRICULTURE.

Porter. Nature and Properties of the Sugar Cane. Smith Elder & Co., London, 1843.

Evans. Sugar Planter's Manual. London, 1847.

Wray. The Practical Sugar Planter. Smith, Elder & Co., London, 1848.

Kerr. Treatise on the Cultivation of the Sugar Cane. London, 1851.

Reynoso. Ensayo Sobre el Cultivo de la Caña de Azucar. Rivadenegra, Madrid, 1865. (Deals with Cuba.)

Delteil. La Canne a Sucre. Chalamel & Co., Paris, 1884. (Deals with Mauritius and Bourbon.)

Bonâme. Culture de la Canne à Sucre. Chalamel & Co., Paris, 1888. (Deals with experimental work at Guadeloupe.)

Semler. Tropische Agrikultur. Wismar, 1888.

Basset. Guide du Planteur des Cannes. Chalamel & Co., Paris, 1889. (Very detailed general treatise.)

Potter. De cultuur van het suikerriet op Java. Arnheim, 1889.

Krüger. Das Zuckerrohr und seine Kultur. Schallehn & Wollbrück, Magdeburg, 1899. (Embodies the earlier results of the Java 'Proef Stations.')

Watts. Introductory Manual for Sugar Growers. Longmans, Green & Co., London, 1893. (Addressed to small planters of the West Indies.)

Stubbs. Sugar Cane. U.S. Dept. Agric., 1897. (Deals with Louisiana.)

Tiemann. The Sugar Cane in Egypt. Norman Rodger, Altrincham, 1903. (Many manurial results.)

Sedgwick. The Sugar Industry in Peru. Trujillo, 1904.

PREFACE.

MANUFACTURE.

Soames. Treatise on the Manufacture of Sugar from the Sugar Cane. London, 1872.

Walkhoff. Die praktische Rübenzuckerfabricant. Brunswick, 1872.

Maumené. Traité de la Fabrication du Sucre. Paris, 1878.

Stammer. Der Dampf in der Zuckerfabrik. Rathke, Magdeburg, 1891.

Cambier. Combustion en Sucrerie Paris, 1892.

Beaudet, Pellet et Saillard. Traité de la Fabrication du Sucre. Paris, 1894.

Von Passauer. Die Zuckerfabrikation. Hartleben, Vienna, 1894.

Evangelista. Fabrication del Azucar de Caña. Madrid, 1895.

Horsin-Déon. Traité theorique et pratique de la Fabrication du Sucre. Paris, 1901.

McIntosh. The Technology of Sugar. Scott, Greenwood & Co., London, 1901.

Foster. Evaporation on the Multiple System. Reed & Sons, Sunderland, 1901.

Hausbrand. Evaporating, Condensing and Cooling Apparatus. Scott, Greenwood & Co., London, 1903.

Abraham. Die Dampfwirtschaft in der Zuckerfabrik. Schallehn & Wollbrück, Magdeburg, 1904.

Claassen. Beet Sugar Manufacture. Wiley & Sons, New York, 1907. (London, Chapman & Hall.)

Ware. Beet Sugar Manufacture and Refining. Wiley & Sons, New York, 1907. (London, Chapman & Hall.)

Wallis-Tayler. Sugar Machinery. Rider & Sons, London, 1908.

Gredinger. Die Raffination des Zuckers. Hartleben, Leipzig, 1908.

Geerligs. Cane Sugar and its Manufacture. Norman Rodger, Altrincham. 1909.

Jones and Scard. The Manufacture of Cane Sugar. Edward Stanford, London, 1909.

Newlands Bros. Sugar. Spon & Co., London, 1909.

CHEMISTRY AND ANALYSIS.

Sidersky. Traité d'Analyse des Matières sucrées. Ballière, Paris, 1892.

Wiechmann. Sugar Analysis. Wiley & Sons, New York, 1893. (London, Chapman & Hall.)

Von Lippmann. Die Chemie der Zuckerarten. Vieweg & Sons, Brunswick, 1895.

Maquenne. Les Sucres et leurs principaux Derivés. Gauttier-Villars, Paris, 1900.

Tucker. Manual of Sugar Analysis. Van Nostrand. New York, 1900.

Landholt. The Optical Rotation of Organic Substances. Chemical Publishing Co., Easton, Pa., 1902.

Frühling and Schulz. Anleitung zur Untersuchung für die Zuckerindustrie. Vieweg & Sons, Brunswick, 1903.

Herrmann. Verlustbestimmung und Betriebeskontrolle der Zuckerfabrication. Schallehn & Wollbrück, Magdeburg, 1903.

Stolle. Handbuch für Zuckerfabrikschemiker. Parey, Berlin, 1904.

Rolfe. The Polariscope in the Chemical Laboratory. Macmillan Co., London and New York, 1904.

Morse. Calculations used in Cane Sugar Factories. Wiley & Sons, New York 1904. (London, Chapman & Hall.)

Tervooren, Methoden van Onderzoek der bij de Java Rietsuikerindustrie voorkomende Producten. Amsterdam, 1904.

Geerligs. Methods of Chemical Control in Cane Sugar Factories in Java. Norman Rodger, Altrincham, 1904.

Heriot. Science in Sugar Production. Norman Rodger, Altrincham, 1907.

Spencer. Handbook for Sugar Manufacturers and their Chemists. Wiley & Sons, New York, 1907. (London, Chapman & Hall.)

Fribourg. Analyse chimique en Sucrerie. Dunod & Pinat, Paris, 1907.

L. Pellet and Métillon. Vade Mecum de Sucrerie. Paris, 1907.

Nikaido. Beet Sugar Making and its Chemical Control. Chemical Publishing Co., Philadelphia, 1909.

Mittelstädt. Technical Calculations for Sugar Works. Wiley & Sons, New York, 1910. (London, Chapman & Hall.)

DISEASES AND ENEMIES.

Wakker and Went. De Ziekten van het Suikerriet op Java. Leyden, 1898.

Van Deventer. De dierlijke Vijanden van het Suikerriet. De Bussy, Amsterdam, 1907.

FERMENTATION.

Hansen. Practical Studies in Fermentation. E. & F. N. Spon, London, 1896.

Lafar. Technical Mycology. Griffin & Sons, London, 1898, 1902, and 1910.

Reynolds Green. The Soluble Ferments and Fermentation. University Press, Cambridge, 1899.

Matthews. Manual of Alcoholic Fermentation. Edward Arnold, London, 1901.

Perrault. Le Rhum. C. Naud, Paris, 1903.

Klöcker. Fermentation Organisms. Longmans & Co., London, 1903.

Jorgensen. The Micro-organisms of Fermentation. Macmillan, London and New York, 1903.

Brandt. Rectification and Distillation of Alcohol. Baird, Philadelphia, 1904.

Herrick. Denatured or Industrial Alcohol. Wiley & Sons, New York, 1907. (London, Chapman & Hall.)

McIntosh. Industrial Alcohol. Scott, Greenwood & Co., London, 1907.

Kohl. Die Hefepilze. Quelle & Myers, Leipzig, 1908.

GENERAL AGRICULTURE.

Hall. The Soil. John Murray, London, 1908.

Hall. Fertilizers. John Murray, London, 1909.

Hilgard. Soils. The Macmillan Co., New York and London, 1907.

The Rural Science Series; various dates and authors. The Macmillan Co., New York and London.

STEAM, &c.

Poole. Calorific Value of Fuels. Wiley & Sons, New York, 1904. (London Chapman & Hall.)

Pullen. Experimental Engineering. Scientific Publishing Co., Manchester, 1904.

Perry. The Steam Engine. Macmillan & Co., London and New York, 1907.

Thurston. A Manual of the Steam Engine. Wiley & Sons, New York, 1907. (London, Chapman & Hall.)

Carpenter. Experimental Engineering. Wiley & Sons, New York, 1909. (London, Chapman & Hall.)

Juptner. Heat, Energy and Fuel. Macraw Publishing Co., New York, 1909.

I feel that I am open to criticism in pretending to recommend books on subjects so indirectly connected with sugar as those included under the last three captions, especially since in these branches of technology there are so many to choose from. I merely mention those which I have used myself to obtain a better understanding of certain phases of the sugar industry.

I know of no more suitable agricultural library for the sugar planter generally than the books included in the " Rural Science Series," published by Macmillan. Each volume is a monograph on some part of agriculture, written by well-known United States experts, which, while not sacrificing accuracy to popularity, treats its subject in a way which will appeal to the non-technically trained planter.

JOURNALS DEVOTED TO THE SUGAR INDUSTRY.

The Sugar Cane. Manchester, 1869-1898.
The International Sugar Journal. Altrincham, Manchester, 1899–
Sugar Planters' Journal (Louisiana Sugar Bowl). New Orleans, 1870-1910.
Modern Sugar Planter. New Orleans, 1910–
The Louisiana Planter. New Orleans, 1887–
The Hawaiian Planters' Monthly. 1882-1909.
The Sugar Journal. Mackay. 1882-1906.
Journal des Fabricants de Sucre. Paris, 1866–
Bulletin de l'Association des Chimistes de Sucrerie. Paris, 1882–
Sucrerie Indigène et Coloniale. Paris, 1886–
Archief voor de Java Suikerindustrie. Soerabaia, 1893–
Centralblatt für die Zuckerindustrie. Magdeburg, 1892–
Die Deutsche Zuckerindustrie. Berlin, 1876–
La Sucrerie Belge. Brussels, 1872–
Österreichisch-Ungarische Zeitschrift für Zuckerindustrie. Vienna, 1873–
Zeitschrift für Zuckerindustrie in Böhmen. Prague, 1872–
Zeitschrift des Vereins der Deutschen Zuckerindustrie. Berlin.
The Australian Sugar Journal. Brisbane, 1909–
The American Sugar Industry and Beet Sugar Gazette. Chicago, 1899–
The Sugar Beet, Philadelphia.

CANE SUGAR.

EXPERIMENT STATIONS DEVOTED WHOLLY OR IN PART TO THE CANE SUGAR INDUSTRY.

British Guiana.—Botanical Gardens. Experiments on Sugar Cane (and other tropical plants) conducted chiefly by J. B. Harrison; results published mainly as reports to the Governor, and often quoted *in extenso* in the *Sugar Cane* and *International Sugar Journal.*

British West Indies.—Experimental work conducted under the direction of the Imperial Department of Agriculture in Barbados, Antigua, St. Kitts. The experimental work in Trinidad, and at the Sugar Experiment Station in Jamaica under the direction of H. H. Cousins, seems less closely associated with the Department. The present Commissioner is Francis Watts, the first having been Sir Daniel Morris; connected with the Department is a large staff of scientists; results are published in *The West Indian Bulletin* as separates.

Cuba.—Estacion Centrale Agronomique. Director, R. G. Osés; previous directors have been F. S. Earle and J. T. Crawley. Results published as Bulletins.

Porto Rico.—Agricultural Experiment Station under the U.S. Dept. Agric. D. W. May, special agent in charge. Results published as Bulletins.

Louisiana.—Experiment Station at Audubon Park, in connection with State University, which also maintains a 'Sugar School.' Director: H. P. Agee; previous directors have been W. Stubbs and W. R. Dodson. Results published as Bulletins.

Hawaii.—Experiment Station of the Hawaiian Sugar Planters' Association. Director: C. F. Eckart; previous directors have been W. Maxwell and R. E. Blouin. Results published as Bulletins.

Argentina.—Sugar Experiment Station in Tucuman. Director R. E. Blouin.

Peru.—Sugar Experiment Station. Director: Cæsar Broggi; previous directors have been T. Sedgwick and F. Zerban. Results published as Bulletins.

Mauritius.—Station Agronomique. Director: P. Bonâme. Results published as Bulletins.

Queensland.—Experiment Station at Mackay. Director: H. Easterby; previous director was W. Maxwell.

India.—Experimental Sugar Farm at Samalkota, Madras. C. A. Barber, Government botanist.

West Java.—Proef Station. Director: J. J. Hazewinkel; previous directors have been H. C. Prinsen Geerligs and F. Went.

East Java.—Proef Station. Director, J. E. van der Stok; previous directors have been G. Kramers, J. K. Wakker, and J. D. Kobus.

Mid. Java.—Proef Station. Director: W. van Deventer; previous directors have been F. Soltwedel and F. Benecke. Results published as separate prints, and also often to be found in the *Archief voor die Java Suikerindustrie.*

<div align="right">NOËL DEERR.</div>

TABLE OF CONTENTS.

APPENDIX.

Tables.

INDEX.

ERRATA.

Page 72, Line 6 from bottom.—For *Eriodendnon* read *Eriodendron*.

Page 84, last line.—For *deeringanum* read *deeringianum*.

Page 88, Line 14.—For *land* read *hand*.

Page 91, Line 17.—Between *in* and *many* insert *so*.

Page 93, Line 11 from bottom.—Delete *and evaporation*.

Page 95, Line 1.—For *Regnoso* read *Reynoso*.

Page 122, Line 13 from bottom.—For *creditable* read *credible*.

Page 136, Line 12.—For *Calcididae* read *Chalcidoidea*.

Page 163, Line 21 from bottom.—For *Wallis Taylor* read *Wallis-Tayler*.

Page 256, Line 16.—For T_1 T_0 read $T_1 - T_0$.

Page 291, last two lines.—The sentence *and the vertical baffles* d *give an up and down circulation to the juice* should be deleted, as the lines marked *d* in the illustration are not baffles but represent the webs of one of the feet which carry the evaporator.

LIST OF PLATES.

CANE SUGAR.

CHAPTER I.

THE CANE.

The sugar cane is a grass belonging (following Engler's classification) to the cohort *Glumifloræ*, natural order *Gramineæ*, tribe *Andropogoneæ*, genus *Saccharum*.

The genus *Saccharum* is divided by Hackel[1] into four sub-genera, (*a*) *Eusaccharum*, (*b*) *Sclerostycha*, (*c*) *Eriochrysis*, (*d*) *Leptosaccharum*. A detailed account of these sub-genera will be found in Krüger's *Das Zuckerrohr*.[2] The cultivated species *Saccharum officinarum*, belongs to the first sub-genus, and is itself divided by Hackel into three groups.

(*a*) *genuinum.* Stem pale green to yellow, darker yellow near the ground. Leaf, grass-green, underside sea-green.

(*b*) *violaceum.* Stem, leaf sheath, lower side of leaves, panicle, violet.

(*c*) *litteratum.* Stem dirty green or yellow, marked with dark red stripes at equal intervals.

In the group *genuinum* is to be included the *S. sinense*, or Chinese cane; the group *litteratum* would include all ribbon canes, but as these sport frequently from self-coloured canes and *vice versa*, the distinction must not be pushed too far. Cordemoy[3] divided the canes known in the island of Bourbon into *S. officinarum*, *S. violaceum*, and *S. sinense* (the Chinese cane); elsewhere in the literature of the cane the purple transparent or Black Cheribon cane is sometimes found incorrectly called *S. violaceum*. The true *S. violaceum* occurs indigenously in the Hawaiian Islands, and is known under the native name of *Manulele*.

The complete cane may be divided into the roots, the root-stock, the stem, the leaf, including leaf-sheath and blade, and the inflorescence.

Stalk.—The stalk of the cane is roughly cylindrical, and varies widely in size, not only with the variety, but also with the conditions of growth; the diameter varies from a minimum of $\frac{1}{2}$ inch to a maximum of 3 inches. The smallest diameter is found in varieties seldom cultivated, as, for example, the Branchu, and among the reed-like canes grown by the ryots of British India, and in some parts called Nanal canes.[4] The greatest is found in the Elephant canes, while the Striped and Black Tanna canes are also of comparatively large girth. The Cheribon canes (*cp. Chapter IV.*) are types of the more slender cultivated canes, while the Bourbon may be considered of average diameter. The length of the stalk in the best cultivated varieties reaches to as much as 20 feet; in others, such as the Bois-rouge and Branchu, the maximum height is very much less. In its early stages of growth the cane is erect, and in some varieties, *e.g.*, Yellow Caledonia or White Tanna, and D. 74, it remains so; in others, such as the Otaheite, it becomes markedly recumbent.
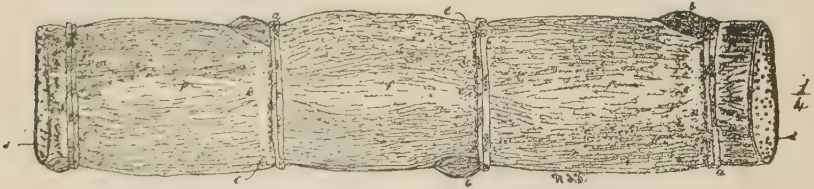
FIG. 1.

The stalk is made up of a series of joints, or internodes, *f*, *Fig. 1*, separated from each other by the nodes, *e*; generally the internodes grow in a continuous line, but occasionally they are 'staggered,' each internode growing at an angle with the next one. The diameter at the node is generally a little larger than at the internode, but in some varieties the internode is notably swollen. The length of the internode may reach to as much as 10 inches, but in well grown Otaheite cane this is generally 4 to 6 inches; the Tanna canes are distinctly short-jointed in proportion to girth, while the B. 147 cane may be taken as an example of a long-jointed variety. The length of joint is influenced largely by conditions of growth; thus it becomes very much reduced when affected by drought or by the cold weather, or when the leaf of the cane has been attacked by disease. The number of internodes may be as many as eighty, or as few as twenty. At each node, and alternately, at opposite sides, is an embryo cane, known as the eye, *b*, *Fig. 1*; it is the size of a pea or larger, and may be triangular, oval, or almost hemispherical; in some varieties, as the Branchu, the eye is swollen and prominent. The eye is covered with a resinous substance and with several layers of bud-scales.

Immediately above each joint appears a ring of semi-opaque whitish spots; this is the zone of adventitious roots; each spot is an embryonic root. In some varieties the roots on the portion above ground under normal conditions develop freely, and form a kind of aerial root; under other conditions this sprouting of the roots is one of the symptoms of the disease known as 'Sereh'; with canes of a recumbent habit sprouting is frequent, and leads to a general weakening of the plant.

The outer surface of the stem is known as the rind; it may be green, yellow, red, purple, white or striped, or blotched in a combination of these colours.

The Root.—The 'root' or root-stock of the cane is merely a prolongation of the stalk beneath the surface of the ground attached to the mother cane in plant cane, or to the mother stalk in ratoon cane. The true roots of the cane spring from the nodes of the stem; they are fibrous, lateral, and very delicate; they ramify in all directions, generally extending from 18 inches to 3 feet from the stem. Stubbs[5] says that the roots do not penetrate very deeply, but Ling Roth[6] mentions roots extending as far downwards as $4\frac{3}{4}$ feet, and Liversedge[6] states that he has seen roots as far down as 8 or 10 feet. The depth to which roots penetrate, however, depends largely on the nature of the soil; they extend furthest in light porous soils. In seasons of drought the roots extend downwards following the water level; on the other hand, in fields with a sour ill-drained sub-soil, the roots, after penetrating downwards, turn back on themselves to the upper surface soil. The cane has no tap root, and its roots have comparatively little hold on the soil.

The Leaf.—The leaves of the cane are alternate and opposite, one at each joint; actually, the leaf consists of two parts, the leaf sheath and the leaf blade. The leaf sheath springs from the node. It completely embraces, at its base, the stalk, and gradually recedes from it; the sheath is colourless or pale green, and about 12 inches long at maturity. The blade is from 3 to 4 feet long, and 2 to 3 inches wide; in colour the leaves are varying shades of green; in some varieties, as in the Cavengerie, variegated or entirely white leaves are often developed. Some Pacific Island canes (*S. violaceum*) have purple leaves. The leaves taper towards the top, and are delicately serrated along the margin; in many varieties *setae* or hairs abound at the base of the leaf, capable of forming painful punctures in the skin; the leaf is traversed longitudinally by a number of veins. The midrib is generally white, but sometimes reddish or purple, and is formed with a channel-like depression in its upper surface. The leaves at maturity fall away from the stalk, and in some varieties separate themselves entirely.

The Flower.—The inflorescence of the cane is a panicle of soft silky spikelets, borne on the end of an elongated peduncle, called the arrow, arising from the terminal vegetative point of the cane.

In *Fig. 2* is given a drawing, enlarged 30 diameters, of a single flower of Lahaina cane. At 1 is the ovary, the growth of which produces the seed; it is ovoid and sessile; from the ovary proceed two styles of a reddish colour, bearing the plumose stigmas, 2. At 3 are the three anthers which produce the pollen, that serves to fertilize the stigmas; at 4 are the two lodicules, the function of which is, by swelling at the proper time, to open the cane blossom; at 5 is the innermost palet of the cane flower, and at 7, 6, and 8 the remaining palet and the glumes; at 9 are the bristles that surround the base of the flower. It is only exceptionally that the cane forms fertile seed. Some varieties never flower, and others do so only in the tropics. The age at which the cane flowers varies from eight to fifteen months, and is dependent on variety and climate and also on time of planting. Flowering takes place at certain definite times of the year, varying in the different cane-growing regions, and if the cane is not sufficiently mature at the flowering time in its first year, no formation of flowers occurs until the second year. In this way a delay of a few weeks in planting will retard flowering for twelve months.

Fig. 2.

4
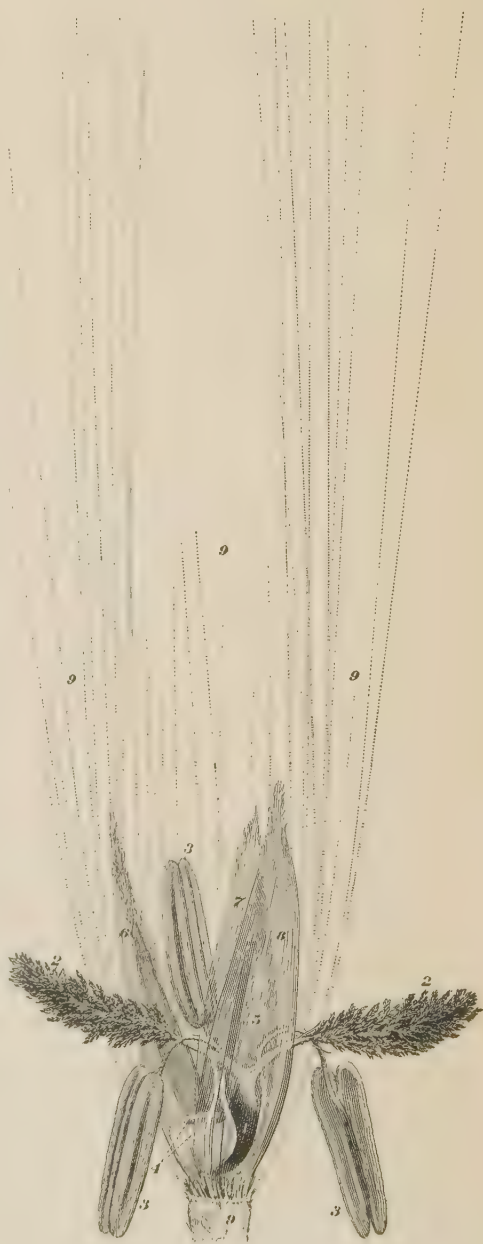
Structure of the Stalk.—
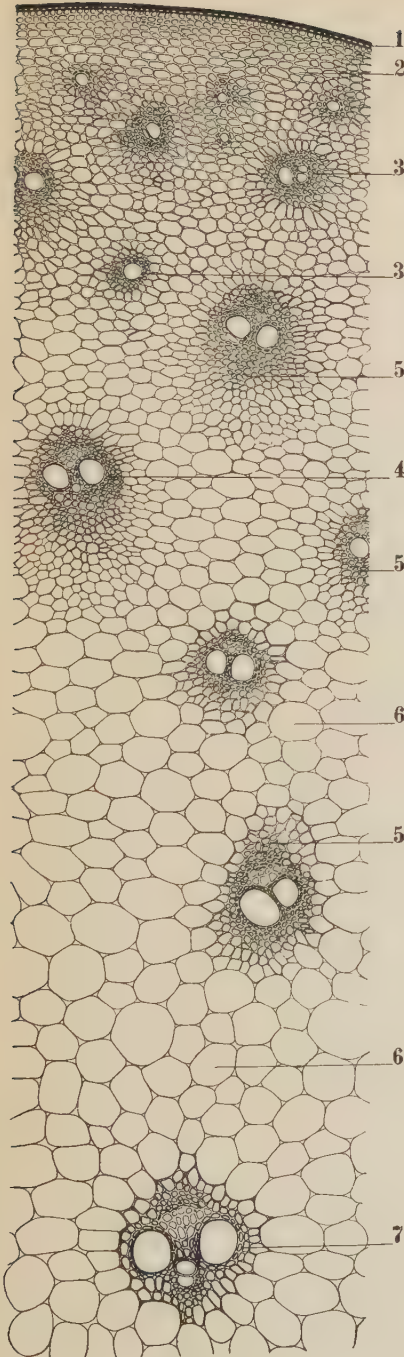
On cutting across a cane it will be seen that it consists roughly of three parts, a hard outer rind, and a mass of softer tissue in the interior, interspersed with fibres, the latter being more frequent about the periphery of the stalk. The rind is made up of a thick epidermis with a strong outer cuticle, impervious to water, and a layer of thick-walled cells; the function of the cuticle is to prevent evaporation of water from the stem of the cane, and to protect the softer interior parts from mechanical injuries; the layer of thick-walled cells gives rigidity and strength to the stem. These thick-walled cells gradually pass into the thin-walled cells of the ground tissue, or parenchyma, which serve to store up the sweet juice of the cane. The fibres are known as the fibro-vascular bundles; they consist of the wood vessels, sieve tubes and companion cells, surrounded by thick-walled fibres.

A cross section of the cane, as seen under the low power of a microscope, is shown in *Fig. 3*.

1. The epidermis, with thick cuticularized walls.

2. Thick-walled ground tissue of the rind.

3. A small vascular bundle; these are found mainly in the outer portion of the stem, and their function is chiefly mechanical.

4. An intermediate bundle with two vessels and a few thin-walled phloem elements.

5. Thick-walled fibres; these are the mechanical elements of the bundles, and are more numerous in the bundles towards the outside.

Fig. 3.

5

6. Thin-walled cells of the ground tissue or parenchyma.

7. A large vascular bundle found toward the centre of the stem.

In *Fig. 4* is shown more highly magnified a bundle corresponding to 7 in *Fig. 3*.

1. A vessel with unbordered pits.

2. An annular vessel.

3. A sieve tube with the companion cells, making up the phloem.
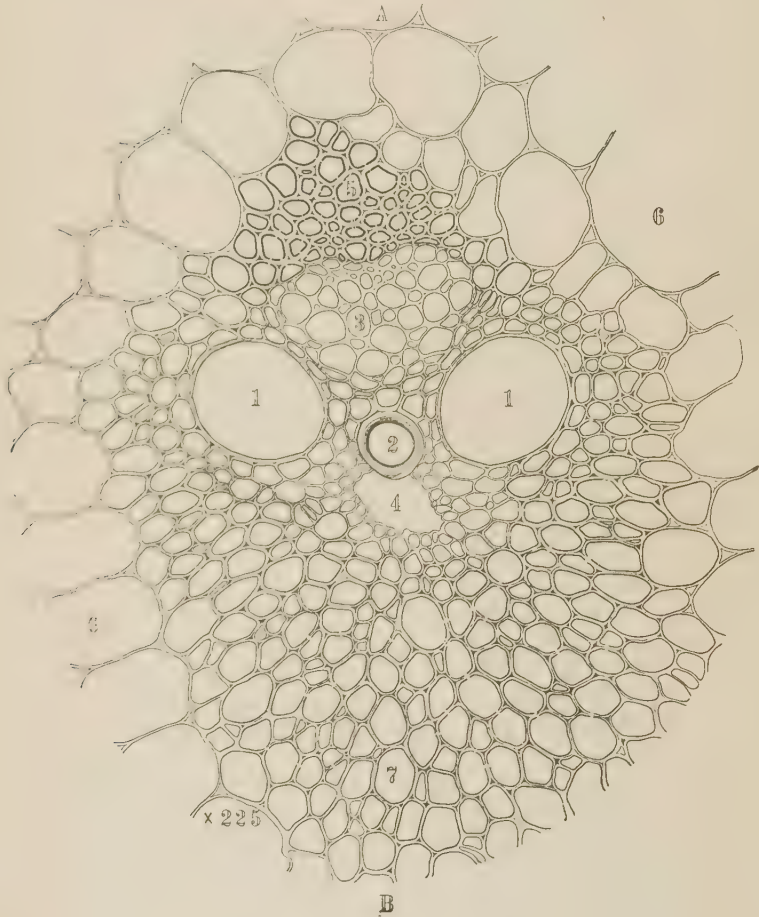
FIG. 4.

4. An intercellular air space.

5 and 7. Thick-walled mechanical elements, the fibres, or sclerenchyma forming a sheath around the bundle.

6. Ground tissue or parenchyma.

When seen in longitudinal section the cells of the parenchyma are found to be rather longer than wide.

6
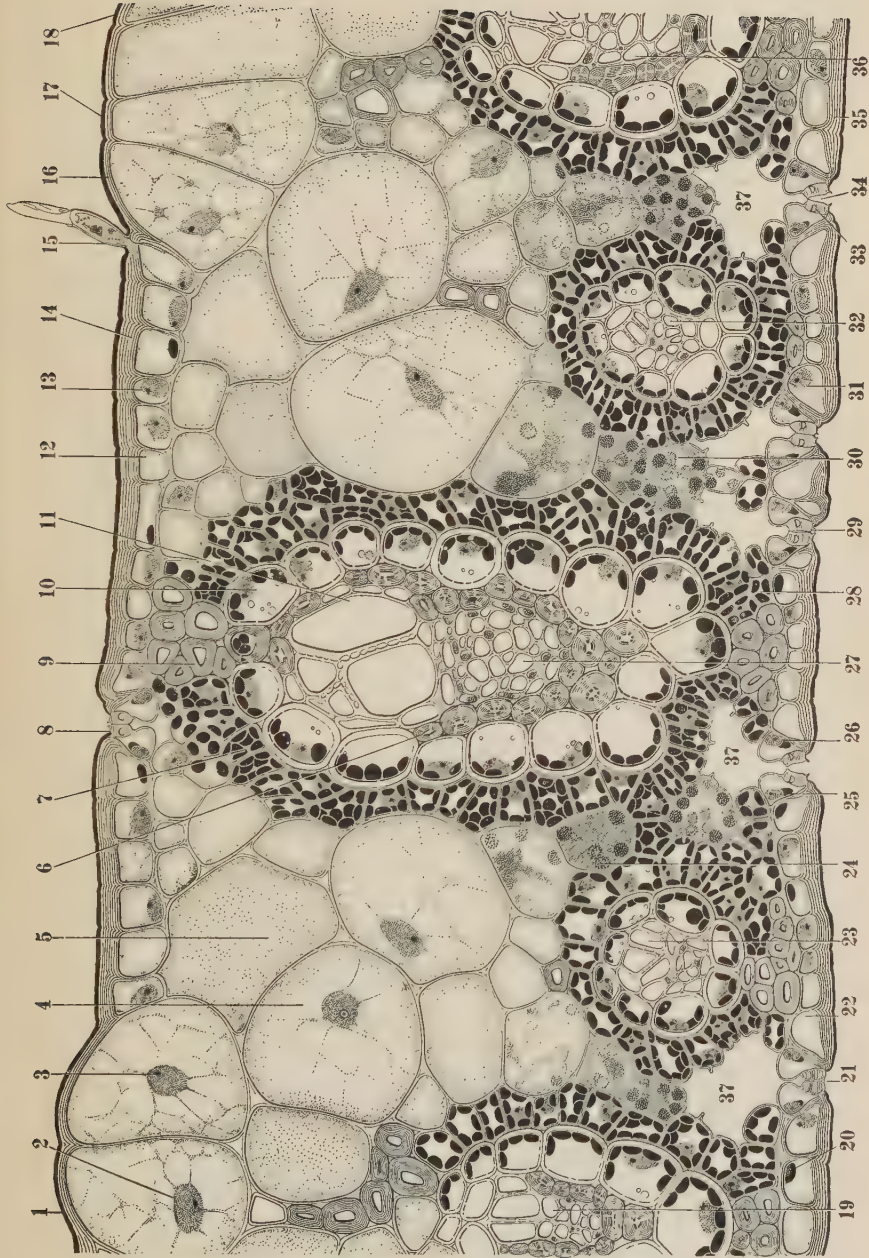
Fig. 5.

(From *Bulletin 4, Division of Pathology and Physiology, H.S.P.A. Exp. Station.*)

7

The sieve tubes seen in longitudinal section are observed to be very elongated cells, with perforated partition walls at intervals in their length; the vessels are continuous throughout their length.

In the internodes the fibro-vascular bundles run parallel, but at the nodes they freely branch and communicate with each other, and pass on into the leaf and into the next internode, passing down right into the roots of the cane.

The physiological function of the fibro-vascular bundles, apart from their mechanical action, is to transmit water, charged with food material, from the root to the leaf of the cane ; this water passes upwards by way of the vessels to the leaf, where it is elaborated, and then passes downwards through the sieve tubes to be either stored in the parenchymatous cells or to be used up in the economy of the growing plant ; the function of the companion cells is not thoroughly understood.

Structure of the Leaf.—In *Fig. 5* is shown a cross section of a leaf of the cane, to which we add Dr. Cobb's explanation of the plate.

" Cross-section of a portion of healthy cane leaf taken half way between the midrib and the margin near the middle of a full-grown but not yet fully lignified leaf. The upper side of the figure, 1 to 18, represents the top surface of the leaf. The fructifications of the leaf-splitting disease occur in positions corresponding to 3, 4, 5. The green chlorophyll bodies are here shown black. It is owing to the destruction of these green bodies in portions of the leaf such as here represented, namely, between the largest vascular bundles, that the leaf takes on a striped appearance. The part of the leaf to be examined was fixed with the vapour of osmic acid while still attached to the cane plant. The fixed portion was differentiated into glycerine and cut in that condition. The drawing was projected from a photograph and sketched. The details were drawn in from the examination of sections either unstained or stained with aniline safranin. The section shows five fibro-vascular bundles, the largest of which is indicated at 6 to 11, the smallest at 23 and 32. Portions of the other two, which are intermediate in size, are shown at 19 and 36. None of these bundles are of the largest size. Bundles fully twice the size of the larger here shown occur in the cane leaf, and such large bundles are characterized by the possession of annular vessels, none of which occur in these smaller bundles. Throughout the illustration structures of the same class are indicated by a similarity in the draughtsmanship, thus the woody cells indicated at 9 are repeated in various parts of the figure, more particularly next to the epidermis of the lower surface.

" 1, a set of so-called motor cells, in this instance composed of two cells, whose nuclei are pointed out at 2 and 3 ; 4, an internal cell of somewhat similar character to that pointed out at 1, 2, and 3 ; 5, another cell of the same class cut in such a way that the nucleus has been removed ; 6, sclerenchymatous cells imparting strength to the fibro-vascular bundle ; 7, one of the layer of parenchymatous cells rich in chloroplasts and immediately surrounding each fibro-vascular bundle ; 8, one of the stomata, found more rarely on the upper than on the lower surface of the leaf ; 9, woody cells imparting strength to the cane leaf, and occurring on the dorsal and ventral side of each fibro-vascular bundle ; 10, one of the cells constituting the sheath of the vascular bundle,—these cells contain chloroplasts arranged along the outsides of their walls ; 11, tracheal vessel ; 12, one of the cells of the upper epidermis ; 13, nucleus of a similar cell ; 14, upper cuticle at its usual thickness ; 15, a two-celled hair on the surface of the leaf ; 16, thinner cuticle of the upper surface of the leaf as it occurs over the so-called motor cells ; 17-18, group of so-called motor cells, consisting in this case of four cells ; 19, fibro-vascular bundle

of intermediate size ; 20, chloroplast in one of the cells of the lower epidermis ; 21, one of the stomatic openings that are abundant on the lower surface of the leaf ; this one is closed,—an open one may be seen at 25-26 ; 22, accessory (?) cell of the stomatic opening ; 23, one of the smallest fibro-vascular bundles ; 24, one of a group of cells very rich in protoplasm which extends between the vascular bundles,—the nearer these cells are to the lower epidermis the denser their protoplasmic contents ; 25-26, protoplasts in the guard cells of the stomatic opening ; 27, one of the sieve tubes,—among these sieve tubes may be seen the smaller companion cells and their protoplasts ; 28, extra chlorophyll-bearing cells outside the single layer surrounding the vascular bundle ; 29, lip of one of the stomatic guard cells ; 30, cell rich in protoplasm, of the same class as 24 ; 31, nucleus of one of the companion (?) guard cells ; 32, fibro-vascular bundle of small size ; 33, apparently a locule in the thickened portion of the wall of the stomatic guard cell ; 34, entrance between the guard cells of the stomatic opening ; 35, cuticle of the lower surface of the leaf ; 36, fibro-vascular bundle of intermediate size ; 37, 37, 37, air chambers immediately above the stomatic openings. Throughout the illustration the nuclei are shown grey, and the nucleoli black. The tissue represented at 24 and 30 is probably primary leaf-tissue, from which during the growth of the leaf the various tissues represented have been differentiated."

Function of the Leaf.—In a sense the leaf may be termed the manufactory of the plant ; under the influence of the chlorophyll and in direct sunlight starch is formed from water and carbon dioxide ; other transformations occur, and the material passes down to be stored in the stem as sugar. The stomata serve for the respiration of the carbon dioxide, and for the secretion of the waste products of the plant ; the fibre, or sclerenchyma, as in the stem, gives rigidity to the leaf. The leaf in its early stages is rolled up, and is opened by the expansion of the motor cells ; in dry weather these cells contract and cause the leaf to roll up, thus exposing a less surface for evaporation.

Structure of the Root.—In *Fig. 6* is shown to a scale of $1\frac{1}{2}$ the end of one of the roots growing from the zone of adventitious roots

X $\left|\frac{1}{2}\right.$

Fig. 6.

in that part of the stem of the cane below ground. Towards the end of the root are seen numerous very fine hairs, and at the extreme end is seen the root cap. In *Figs. 7* and *8* are given longitudinal and cross-sectional views of the root, the longitudinal view being taken through the apical point ; *rc* is the root cap, *m* is the layer of meristematic tissue, *rh* a root hair formed from the piliferous layer on the extreme outer layer of the root ; *cor* is the cortex, *st* the central cylinder, *v* a developing wood vessel, and *x* a larger wood vessel.
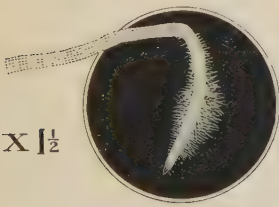
The root cap on the exterior consists of dead cells, and is continually being renewed from the interior by the layer of meristematic tissue from which also arise by a continual process of cell sub-division all the other tissues of the root.

Function of the Root.—The functions of the root are two-fold; the root hairs closely envelop particles of soil, thereby maintaining the hold of the plant on the soil, and, secondly, the root hairs absorb water and plant food from the soil and transmit it to the other parts of the growing plant.

Physiology of the Cane.—The physiology of the cane has been studied chiefly by Went[7] who concluded
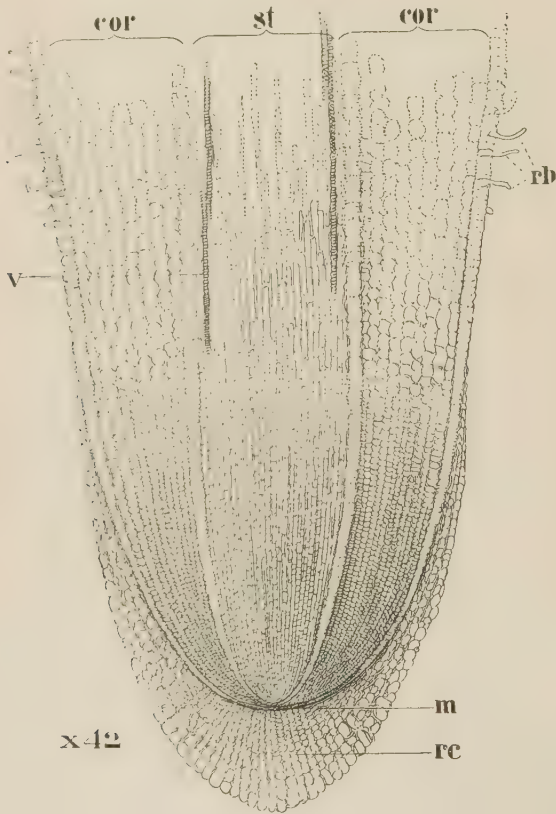
Fig. 7.

1. That cane sugar is the chief product of assimilation in the cane leaves, dextrose and levulose only being formed by inversion; maltose was not identified; the proportion of sucrose, dextrose, and levulose in the juice of the leaves is as $4 : 2 : 1$.

2. The sugar of the leaves is carried during the night in the form of invert sugar to the stem and deposited round the cellular vessels as starch.

3. The parenchyma of the leaves, and above all of the central rib, is very rich in sugar and tannin, while the cellular vessels contain less sugar and tannin and more albumenoids.

4. Generally those parts of the plant undergoing cellular division contain much starch and albumen and little sugar ; where cellular division is restricted the reverse obtains.

In the life history of the stalk the following phases are distinguished :—

1. In very young parts of the stalk only starch or albumen are present, which are consumed little by little in the formation of cellulose.

2. In young, rapidly-growing parts of the stalk, the cane sugar brought down by the leaf is inverted, and whereas in the leaf the proportions of sucrose, dextrose, and levulose were as 4 : 2 : 1, in the young joints the proportions
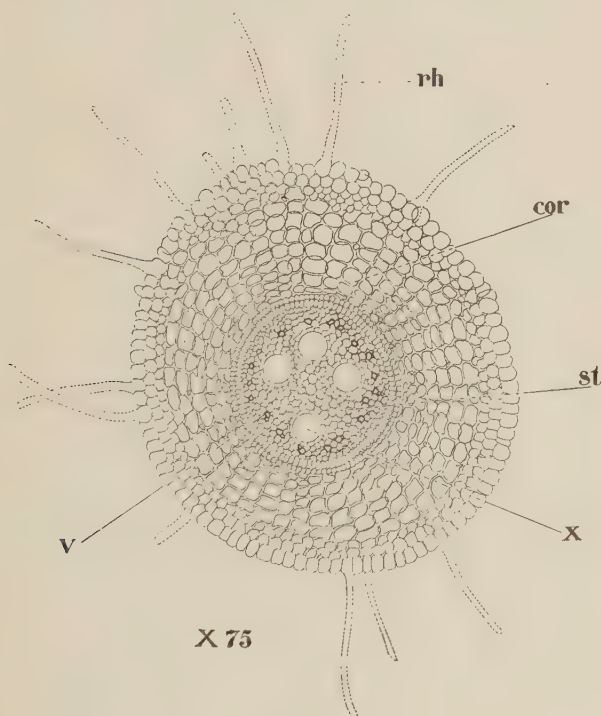
Fig. 8.

are ·8 : 1 : 1. A part of the invert sugar is used up in the formation of fibre, a part unites with the amides to form albumen, and a part is deposited as starch. In consequence of the inversion, the osmotic pressure is raised and this tends to favour the absorption of plant food.

3. In older joints the sucrose formed in the leaf remains unchanged when it reaches the joint and the reducing sugars are used up, partly in respiration, or, perhaps, are partly by a reverted enzyme action converted into sucrose ; of the reducing sugars that remain, the dextrose is generally in excess.

4. When the stalks are developed, the accumulated invert sugar is converted to sucrose; of the invert sugar remaining the dextrose is generally in excess.

5. When the stalks are ripe the leaves die and the accumulation of sugar gradually ceases; the remainder of the invert sugar is changed to sucrose, eventually only traces of invert sugar remaining.

6. When the stalks are over-ripe the sucrose is converted into invert sugar, but this change does not prevent the younger parts of the cane accumulating sugar.

The roots of the cane only contain sugar when very young; as the age of the cane increases the sugar is converted into starch and cellulose.

Starch has been recognised in cane leaves cut in the day time.

REFERENCES IN CHAPTER I.

1. *The True Grasses*, p. 15.

2. *Das Zuckerrohr*, pp. 5-24.

3. Quoted by Delteil in *Le Canne à Sucre*, p. 14.

4. *I. S. J.*, 45.

5. Stubbs' *Sugar Cane*, p. 13.

6. Quoted by Lock and Newlands in *Sugar*.

7. *Arch.* IV., 525.

The blocks whence Figs. 2–6 were printed have been lent by the Experiment Station of the Hawaiian Sugar Planters' Association. They have previously appeared in the Bulletins issued by the H.S.P.A. Experiment Station; the original drawings were made by Mr. E. M. Grosse, Mr. W. E. Chambers, and Miss Frieda Cobb, under the direction of Dr. N. A. Cobb.

CHAPTER II.

THE COMPOSITION OF THE CANE.

The cane is not by any means of even approximately uniform composition, but differs with variety and conditions of growth. The limits of composition of single canes may be estimated as :—Water, 69 per cent. to 75 per cent. ; Saccharose, 7 per cent. to 20 per cent. ; reducing sugars, 0 to 2 per cent. ; fibre, 8 per cent. to 16 per cent. ; ash, ·3 per cent. to ·8 per cent. ; organic non-sugar, ·5 per cent. to 1 per cent.*

The percentage of sugar in the cane, though to some extent dependent on variety, is by no means entirely so ; conditions of soil and climate have a great influence. In Demerara, where up to 1900 practically the whole crop was Bourbon cane, canes grown on virgin soil gave heavy crops, with generally less than 11 per cent. of sugar, the sugar percentage of canes grown on older land often rising to 14 per cent. or more. As an instance of variety affecting composition the difference between Lahaina and Yellow Caledonia cane grown under the same conditions in Hawaii may be cited, the former almost invariably affording a sweeter purer juice, and also containing less fibre ; amongst other canes that by comparison with the Lahaina (Bourbon, Otaheite, &c.) afford a poor juice may be cited the Elephant cane, the Cavengeric (Po-a-ole, Altamattie, Giant Claret, &c.) and the Salangore.

When seedling canes were first grown, evidence was obtained on the small scale that high sugar content was an inherent property of certain varieties, of which D. 74 may be quoted ; on the estate scale, however, the results were very disappointing. Latterly, however, much evidence has accumulated that the cane B. 208 is one of high saccharine content and similar results have been obtained in Java ; in addition it has been shown by Kobus that it is possible to obtain a strain of canes of high sugar content by a process of chemical selection.

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* Mr. Prinsen Geerligs on p. 94 of *Cane Sugar and its Manufacture* gives the following limits : Sucrose, 11 per cent. to 16 per cent. ; reducing sugar, ·4 per cent. to 1·5 per cent. ; Fibre, 10 per cent. to 15 per cent. ; Ash, ·5 per cent. to 1 per cent. and elsewhere protests against exaggerated statements of the sucrose content of the cane. The crop averages for canes raised in the arid areas of the Hawaiian Islands under irrigation often reach 16 per. cent. and for single weeks may be as much as 18 per cent., single canes even containing 20 per cent. On the other hand the writer has met with large areas of year old plant cane in Demerara containing only 7 per cent. and with reducing sugars over 2 per cent.

Distribution of Sugar in the Cane.—The cane is not of uniform composition throughout its length, and it is this property that makes it a matter of such difficulty to obtain representative analyses of large quantities of cane. The annexed table of analyses by Bonâme[2] illustrates this point.

A. Plant cane, imperfectly ripe and still in full vegetation.

B. Second ratoons, 11 months old.

C. Fourth ratoons in vegetation.

D. First ratoons, 11 months old.

E. Creole cane, the stalk 1 metre long and 10 cm. in circumference.

F. Plant cane, very ripe, 14 months old.

		Degree Beaumé.	Sugar Per cent.	Glucose Per cent.
A.	Lower part	9·05	13·74	1·78
	Middle ,,	9·5	14·11	2·44
	Upper ,,	8·2	8·85	4·11
	White top	7·5	4·01	6·57
B.	Lower third	—	16·20	·94
	Middle ,,	—	15·40	1·59
	Upper ,,	—	13·60	1·75
C.	White top	—	9·07	1·95
	Upper part	—	16·52	·78
	Lower ,,	—	19·44	·37
D.	Lowest fourth	11·1	20·73	·37
	Lower middle fourth	11·1	20·41	·37
	Upper ,, ,,	10·7	19·44	·65
	Upper fourth	10·4	17·82	·52
	White top	9·2	14·90	·71
E.	Lower third	—	8·74	3·56
	Middle ,,	—	1·24	4·38
	Upper ,,	—	4·62	4·56
F.	Lowest fourth	12·3	22·68	·51
	Lower middle fourth	12·3	22·68	·52
	Upper ,, ,,	12·3	22·68	·52
	Upper fourth	12·0	22·03	·53
	White top	10·0	16·84	·70

The variation in composition of the juice in the nodes and internodes is given by Bonâme.

Nodes {	Sugar	13·34	12·74	16·73
	Glucose	·29	·28	·31
Internodes {	Sugar	16·51	16·80	19·72
	Glucose	·60	·84	·48

Stubbs[2] gives the following as the result of analyses of twenty stalks of purple cane :—

	Degree Brix.	Sugar.	Glucose.	Solids not sugar.	Fibre.
Nodes	15·94	12·6	·13	3·21	16·5
Internodes	17·40	15·5	·94	·96	8·00

The great variation in composition of juice at nodes and internodes is well shown in the tables quoted above and an explanation given of the decreased sugar content of second mill juice compared with first mill juice, the more woody nodes only yielding their juice on a more powerful crushing.

The Reducing Sugars of the Cane.—The reducing sugars of the cane consist almost wholly of dextrose and levulose. Wiley, working on sub-tropical cane, found both these sugars, but Winter, in Java, with tropical cane, found only dextrose. Geerligs,[4] however, showed that in Java dextrose and levulose are both formed, but that the latter is used up more rapidly in the plant's economy, and tends to disappear, and this observation has also been made by C. A. Browne,[6] in Louisiana. Finally, as has been shown by Wiley,[4] the reducing sugars may be entirely absent in perfectly ripe cane. In over-ripe cane they again appear, due to the inversion of the saccharose.

The Non-Sugars of the Cane.—The following bodies have been identified in the cane; a doubtful identification is shown by italics :—

Inorganic bases : potash, soda, lime, magnesia, iron, alumina, manganese oxide, titanium oxide.

Inorganic acids : sulphuric, phosphoric, silica.

Organic Acids : malic, succinic, oxalic, glycolic, acetic (in damaged cane), *citric, tartaric, aconitic.*

Nitrogenous bodies : albumen, nucleins, albumoses, peptones, amines, amido acids, xanthine bases, lecithins.

Non-nitrogenous bodies : Fat, wax, chlorophyll, anthocyan, pectin, xylan, araban, gum, cellulose, lignin.

Composition of different Parts of the Cane.—According to C. A. Browne[6] the average composition of Louisiana cane is as shown in the following table :—

	Leaves. Per cent.	Stalks. Per cent.	Roots. Per cent.	Seeds. Per cent.
Water	74·38 ..	74·96 ..	68·79 ..	11·03
Ash	2·23 ..	0·64 ..	1·87 ..	5·22
Fat and Wax	0·69 ..	0·38 ..	0·54 ..	2·01
Crude Cellulose	9·18 ..	4·86 ..	9·58 ..	25·51
Pentosans....	5·49 ..	3·04 ..	7·04 ..	26·26
Lignin	4·13 ..	2·14 ..	4·25 ..	21·50
Sugars	2·20 ..	13·40 ..	6·34 ..	—
Nitrogenous bodies ..	1·70 ..	0·58 ..	1·59 ..	8·47

The Nitrogenous Bodies of the Cane.—These have been found by C. A. Browne[6] to be thus divided in Louisiana cane :—

	Per cent. on cane.
Albumen (coagulable and soluble in pepsin)	·059
Nucleins (coagulable and insoluble in pepsin)	·040
Albumose and peptones (not coagulable)	·033
Amido acids (aspartic acid)	·145
Amido acid amids (asparagine)	·232
Ammonia (NH$_3$)	·008
Nitric acid	·071
Total nitrogenous bodies	·588

Shorey has made very detailed studies of the nitrogenous bodies in the cane. He finds that the principal amide is glycocoll[7], and he failed to identify asparagin; glycocoll being undecomposed on boiling in alkaline solution passes on to the molasses. By precipitation with phosphotungstic acid after removal of the albuminoids by copper oxide, he isolated a mixture of lecithins[8] the alkaloidal basis of which he identified as betaine and choline; the lecithins being decomposed on boiling accounts in his opinion for the presence of fats in the second and third bodies of the evaporators. The only xanthine base found by Shorey was guanine[9], which accumulates like the glycocoll in the molasses.

Fibre.—By fibre is meant that portion of the cane insoluble in water; C. A. Browne[6] found the crude fibre to consist of:—

	Crude Fibre in		
	Pith.	Bundles.	Rind.
	Per cent.	Per cent.	Per cent.
Ash	1·68 ..	3·58 ..	1·64
Fat and Wax	·41 ..	·72 ..	·98
Protein	1·94 ..	2·00 ..	2·19
Cellulose (Cross & Bevan).. ..	49·00 ..	50·00 ..	51·09
Pentosans (Furfuroids)	32·04 ..	28·67 ..	26·93
Lignin..	14·93 ..	15·03 ..	17·17

and when calculated to 100 parts pure cane fibre, protein, ash and fat free,

	Per cent.
Cellulose (including oxycellulose)	55
Pentosans (xylan and araban)	20
Lignin	15
Acetic acid	6

Similar results were obtained by Geerligs[10] in Java.

Cane Wax.—This body occurs on the rind of the cane and in some varieties is almost absent; it has been exhaustively studied by Wijnberg.[11] Generally dry press cake contains up to 10 per cent. to 12 per cent. of wax; about 70 per cent. of the crude body consists of the glycerides of oleic, linolic, palmitic, and stearic acids, with hydroxyacids, resinacids, lecithin, phylosterol, aromatic and colouring matters; the remaining 30 per cent. contains about 45 per cent. of myricyl alcohol and 35 per cent. of a non-primary crystalline alcohol, with at least one other body. These data refer to the benzene soluble bodies in press cake. At the moment of writing attention is being paid to the commercial recovery of this body.

Pectin.—This body, also referred to as *gums* and *alcoholic precipitate*, is of uncertain and indefinite composition; it occurs in the cane up to as much

FIG. 9.
BOURBON.

3
4
SIZE

PLATE I

as ·2 per cent., and is present in largest quantity in unripe cane. It is soluble in water and insoluble in acidified alcohol; the lime compound of pectin is moderately soluble in water, and more so in sugar solution; some of the pectinous bodies are precipitated by lime in the process of manufacture, and some are found in the molasses.

REFERENCES IN CHAPTER II.

1. *I.S.J.*, 90 and 91.
2. *Cultur de la Canne à Sucre*, p. 154.
3. Stubbs' *Sugar Cane*, p. 89.
4. Stubbs' *Sugar Cane*, 333.
5. *I.S.J.*, 33.
6. *Louisiana Bulletin*, 91.
7. *J.A.C.S.*, 19, page 881.
8. *J.A.C.S.*, 20, p. 113.
9. *J.A.C.S.*, 21, p. 809.
10. *I.S.J.*, 96, p. 619.
11. Abs. in *Jour. Soc. Chem. Ind.*, *28*, 991.

CHAPTER III.

RANGE AND CLIMATE.

The sugar cane is essentially a tropical plant, but under certain favourable conditions is successfully cultivated in sub-tropical districts.

The extreme limits of its cultivation are the South of Spain (36°–37° N.), Japan (30°–35° N.), and Georgia, U.S.A. (32° N.), on the one side, and Cape Colony (29°–30° S.), and New Zealand (35°–37° S.) on the other. The other countries where the cane forms a staple product are Madeira (33° N.), Java (6°–8° N.), the Hawaiian Islands (18°–22° N.), British India (10°–30° N.), the West Indies (8°–22° N.), including Cuba, Porto Rico, Jamaica, Martinique, Guadeloupe, St. Kitts, St. Thomas, Antigua, St. Croix, Barbados, Trinidad; British and Dutch Guiana (6°–8° N.), Brazil (0°–20° S.), Louisiana (30° N.), Egypt (22°–30° N.), Central America (8°–20° N.), the Philippines (5°–18° N.), Queensland and New South Wales (10°–35° S.), Mauritius and Bourbon (20°–22° S.), Natal (30° S.), Fiji (22° S.), Formosa (22° N.), Southern China (10°–30° N.), the Straits Settlements (0°–10° N.), Peru (5°–22° S.), Argentina (22°–25° S.).

Humidity.—Starting with Wray (1848) a warm and moist climate has been stated to be specific to the successful growth of the cane, and proximity to the sea often has been given as a favourable factor. Thus Wray[1] writes: "The climate most congenial to the cane is of a warm and moist character, with moderate intervals of hot, dry weather, attempered by the refreshing sea breezes. It has always been found to grow most luxuriantly on islands, and along the sea coasts of the mainland; which leads us to conclude that the saline particles borne on the sea breeze exercise a powerful effect on the growth of the plant."

Delteil[2] expresses himself in terms similar to Wray. "The sugar cane, originating from India and Eastern Asia, demands a warm, moderately moist climate, with intervals of dry heat; it loves sea breezes because of the particles of salt which are carried to the fields and increase their fertility."

According to Bonâme,[3] "a warm and moist climate is the most favourable to the growth of the cane, and it is in islands and on the sea coast that the most luxuriant plantations are seen, for it is there that are found together the conditions of heat and moisture demanded for its greatest development."

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Stubbs[4] in commenting on these statements is most certainly right in attributing the maritime position of many sugar districts to economic reasons; an inland sugar estate in a tropical country would be deprived of means of access to the world's markets. Where a local market exists the cane is grown successfully in districts remote from the sea, as in Queensland, Brazil, Argentina, and India; and some insular districts, such as certain of the Hawaiian Islands, have a climate the reverse of moist.

Temperature.—The effect of temperature on the cane is very complex; the rate of growth, the time to maturity and the composition of the cane are all affected. The rate of growth is probably directly connected with the temperature, increasing as the temperature rises; exact measurements are difficult to make; in the more equatorial cane growing districts the temperature variation is so small that differences in the growth at different periods of the year cannot be noticed. Definite measurements have been made in Hawaii by C. F. Eckart[5] in connection with varieties; the length and diameter of internodes formed during the hot and cool seasons were measured; generally the length of the internodes formed during the cold season was more than 30 per cent. and less than 50 per cent. less than those formed during the hot season; the diameter of the internodes formed during the cold season was also less than that of those formed during the hot season. The time to maturity as indicated by the appearance of the arrow is directly influenced by the temperature; in equatorial districts, such as Demerara, Bourbon canes planted in December arrow in September, the time from planting to arrowing being approximately 270 days. In districts just within the tropics, such as the Hawaiian Islands or Mauritius, the arrow in the Lahaina plant cane will not appear for approximately 500 days; the colder climate takes a longer period to bring the plant to maturity, but the total amount of heat received in the two instances is very similar.

In the extra tropical cane growing districts, such as Louisiana, the low temperature of the winter months prevents the cane being turned over from one season to the next, and the crop has to be grown in a short period of growth; an immature cane, combined with low sugar content and high content of reducing sugars, results; the reducing sugars in this case representing material which would be converted into cane sugar if a longer period of growth were possible.

On the other hand, in districts where a high temperature continually prevails, such as in Demerara, a cane low in sugar and high in impurities and reducing sugars frequently occurs; in such districts there is a continuous growth of the cane, and the crop as it reaches the mill will in general consist of cane of all periods of growth, over-matured, ripe, and in full vegetative vigour.

A very sweet and pure cane is found in those districts where the average temperature is such that a longer period is taken to maturity, and where a season cold enough to check the growth of the cane occurs; when this arrest of growth happens, the energy of the cane is presumably directed towards the elaboration of the material already formed, rather than to the formation of new substance; it is in the districts lying on the confines of the tropics that this phenomenon happens.

Rainfall.—The amount of water essential to the best growth of the cane is discussed in the chapter on irrigation. Under natural conditions an excessive rainfall results in a cane of low sugar content, a deficiency in rainfall resulting in a cane with much fibre. The optimum rainfall is, of course, directly correlated to the prevailing temperature, the soil evaporation increasing with rise in temperature; thus Stubbs,[6] referring to Louisiana conditions, gives an annual rainfall of about 60 inches as most advantageous, of which about 45 inches should fall in the wet or growing season, and about 15 inches during the dry. Such an annual rainfall would be classed as a severe drought in Demerara, where a precipitation of about 100 inches results in the maximum crop; the rainy season there should commence in mid December, and continue without prolonged intervals of drought to the end of July, the earlier months of the year being dry enough to allow of the cultivation of the heavy clay soils. A heavy rain immediately before harvest is reflected in a diluted juice, the vessels which carry plant food being then full of water at the moment of cutting.

Wind.—The chief effect of winds in regard to agriculture, whether of the cane or otherwise, is concerned with the removal of soil moisture; the more frequently the stratum of air over a soil is removed, the greater is the soil evaporation. The point of the compass from which the wind blows is of influence in this connection; a wind blowing from the sea to the land conveys air heavily charged with moisture, increasing the humidity of the atmosphere, and lessening the tendency to soil evaporation; it is probably for this reason that in Demerara surface evaporation from exposed shallow vessels is small compared with what would be expected from temperature conditions alone. The surface evaporation there is 35·12 inches, per annum, compared with 31·04 inches at Oxford, and 82·28 inches at Bombay.[7] In Demerara the prevailing winds are the North-east Trades, blowing directly from the Atlantic, with no intervening mountains to cause a deposit of water as rain. Maxwell[8] in Hawaii found that 120 square inches of exposed area evaporated in 270 days 33,480 grams. of water, the relative humidity being 79·5, and the average temperature 79·5; this is equivalent to an evaporation of 28·4 inches per annum. Under equal conditions, but with the water protected from the wind,

the evaporation was equal to 12·1 inches per annum. This experiment was made to estimate the effect of wind on soil moisture; in this determination the wind-exposed water was sheltered from the direct rays of the sun.

When the wind reaches a high velocity mechanical damage to the leaves is very evident, and when the wind becomes cyclonic the whole growing crop may be destroyed, as happened in Mauritius in 1892.

To a certain extent the effects of wind may be mitigated by the judicious planting of wind breaks. Such a wind break of *Casuarina equisetifolia* is to be found on a very large scale at Lihue Plantation in the Hawaiian Islands. The sea front of this estate is girdled by a wind break extending for several miles, and covering altogether 600 acres. When in Demerara, the writer always felt that no inconsiderable benefit would accrue if on those flat, wind-swept estates all the *cross dams* and other available areas were planted with trees.

Variety and Climate.—It may be said that all varieties of cane attain their maximum growth in the more essentially tropical districts; some varieties, on the other hand, fail entirely when removed to these latter districts.

It seems probable that adaptability to a colder climate is a characteristic of the red and purple canes. In a subsequent chapter it will be shown that the light and dark Cheribon (Transparent, Bamboo, &c.,) canes in all probability originated from striped canes. Stubbs[9] states that in the relatively cold climate of Louisiana a plantation of striped canes if not renewed tends to pass into one of all purple canes, and classes this phenomenon as a case of the "survival of the fittest," attributing to the purple colour a greater capacity to absorb heat.

The cane known as Cavengérie, Port Mackay (in Mauritius), Louzier (in the Argentine), Po-a-ole (in the West Indies), is also another instance of a dark coloured cane being adapted to a cold climate. In the less tropical portions of South America this variety is one of the canes most widely grown.

In the Hawaiian Islands the Lahaina cane forms the bulk of the crop on the irrigated plantations in the arid districts, chiefly at a low altitude; it is replaced by the Yellow Caledonia on the rainfall plantations situated mainly at a higher level, and hence with a colder climate. A peculiar case of suitability to climate is to be found in the D. 74 cane which has conferred so great a benefit on the Louisiana industry; suitability to the climate of Louisiana is in this case due to the early maturity habit of the variety. The adaptability of a variety to a cold climate does not in any way imply that it will fail in

a hotter one, as the purple cane of Louisiana formed for many years, under the name of Cheribon, the standard cane of tropical Java.

A further instance of the connection between variety and climate is to be found in the success of the Uba cane in extra tropical Natal and Madeira, localities unsuitable for the growth of the canes of the Otaheite type; in fact it may be said that every locality is suited for the growth of one or another variety to its best advantage.

REFERENCES IN CHAPTER III.

1. *The Practical Sugar Planter*, p. 48.
2. *Le Canne à Sucre*, p. 37.
3. *Culture de la Canne à Sucre*, p. 13.
4. Stubbs' *Sugar Cane*, p. 13.
5. *Bull. 17, Agric. H.S.P.A.*
6. Stubbs' *Sugar Cane*, p. 31.
7. Hilgard's *Soils*, p. 256.
8. *Bull. 90, U.S.D.A.*, p. 9.
9. Stubbs' *Sugar Cane*, p. 77.

CHAPTER IV.

VARIETIES OF THE CANE.

Owing to lack of communication between sugar-growing districts, and to absence of systematized work in all but the more recent phases of the cane sugar industry, great confusion has arisen in the nomenclature ; a cane introduced from one district to a second receives a name usually connecting it with the introducer or with the district whence brought ; the same cane travels from the second district to a third, and there receives a name connecting it with the second district, and not with its original home. On the other hand, two different canes may be introduced from one district into two widely separated countries, and in this case they may receive, in both cases, the same name. In these ways, names for the principal varieties have multiplied until a variety may have as many as twenty titles, and to add to the confusion some of these titles may be applied to other quite distinct varieties.

Much of the confusion has been cleared away by means of the detailed descriptive lists of canes growing in the botanical gardens and experiment stations in Jamaica, Louisiana, Demerara, and Java, published by Fawcett[1], Stubbs[2], Harrison & Jenman[3], and by Soltwedel[4]. Comparison of these lists lays bare many irregularities due to the causes mentioned above. Eckart and Deerr[5] made an effort to reconcile many of these statements, and to collate the literature of the subject. Below are described, in detail, the more important varieties of the sugar cane.

The Otaheite Cane.—Wray[6], in 1848, described two canes under this topographical heading,—the yellow and the purple striped; in this section only the former is considered. From the island of Otaheite a yellow cane or canes has been introduced into many cane-growing districts; instances are that by Captain Bligh into Jamaica in the 18th century, and into Hawaii by Captain Pardon Edwards in 1854 ; also in the 18th century a yellow cane was introduced into the French West Indies from the island of Bourbon. Wray gives the presumptive origin of this last as the Malabar coast of India.

The principal names that have been applied or identified as belonging to this cane are Bourbon (British West Indies), Lahaina (Hawaii), Otaheite (Cuba and Java), Louzier, Keni-keni, Portii, Cuban. China, Bamboo II., and Cayenne are also names connected with this cane.

There is considerable reason for supposing that this cane includes two very similar but distinct varieties, for Stubbs[2] identifies the canes growing at Audubon Park under the names of Yellow, Otaheite and Louzier ; and those

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under the name of Portii, Lahaina and Keni-keni. Harrison and Jenman[3] identify Bourbon, Cuban, Lahaina, and Otaheite, but separate Keni-keni. This difference of opinion can be reconciled by assuming that there are two similar canes, and that the names proper to one variety have been applied to the other; great probability is lent to this view in the following account of the origin of the Lahaina cane :—

Mr. D. D. Baldwin, in a letter appearing in the *Hawaiian Planters' Monthly*, for May, 1882, states that in 1854 Captain Edwards, in the ship 'George Washington,' brought *two* varieties of cane from Otaheite (*not* from the Marquesas) ; these two varieties are now (1882) known as Cuban and Lahaina, the Cuban also obtaining the name 'Oudinot.' To the Cuban was also applied the term Keni-keni, from the native term *kinikini*, ' numerous,' in reference to the prolific nature of the cane.

Mr. Baldwin thus distinguishes between these two canes.

Lahaina.—Long straight leaves of light colour, heavily aculeated, or covered with prickles at the base, with small round prominent buds.

Cuban.—Leaves of darker green, bending down in graceful curves, with no prickles, and large triangular buds, located in little cavities on the side of the cane stalk.

Mr. Baldwin further states that in 1861-62, Cuban was the favourite cane, and that it afterwards gave way to Lahaina, the latter possessing these advantages : rapid growth, deep rooting, hard rind when mature, superior richness of juice, firm compact fibre, making the trash easy to handle, and enhancing its value as fuel.

The Louzier cane is one that has been and still is extensively grown in Mauritius, and its origin is entirely different. In a letter received by the writer in 1908, from M. Auguste Villele, of Mauritius, its origin is stated as follows :—In 1868 or 1869, M. Lavignac introduced into Mauritius several varieties of cane from New Caledonia, amongst which was the Mignonne, a red and green striped cane. This cane when cultivated was noticed by M. Louzier to throw sports, and from a yellow sport was developed the cane which for many years formed the standard cane of Mauritius. It is certain that the Louzier cane, which has travelled from Mauritius to other districts, is not to be distinguished from the Yellow Otaheite cane (or canes) ; and the writer, who has seen the Bourbon, the Lahaina, and the Louzier on the large scale in Demerara, in Hawaii, and in Mauritius, has no hesitation in saying that grown on the large scale they are indistinguishable. It is then reasonable to suppose that the Lahaina and Bourbon canes, although introduced as self-coloured canes, were originally in Otaheite sports from the cane introduced into Mauritius in 1868 or 1869 under the name Mignonne, and that in Otaheite the latter was cultivated by the natives as a separate cane.

The following irregularities may be noted in connection with the names applied to this cane (or canes) : —

1. In Réunion a purple cane (the Black Cheribon, &c., *see below*) is called Otaheite.

2. The Bourbon, described by Stubbs as so called in the collection at Audubon Park, is the White Cheribon, &c., as described below.

3. In Jamaica the Otaheite cane is, according to Cousins,[9] the White Transparent, *i.e.*, White Cheribon.

4. The name Portii was originally applied to a chalky grey-coloured cane in Mauritius.

5. Owing to confusion in transport of the original cuttings, the name Louzier in Brazil is applied to the cane described below as Cavengerie.

6. The Loethers (Louzier) cane of Java, as figured and described by Soltwedel and by Krüger,[7] is a brown cane distinct from the Otaheite.* Prinsen Geerligs states that a cane called Bourbon was introduced into Java from the Straits in 1890, and describes it as being very similar to the Cheribon.

This cane is shown in *Fig. 9*†; the illustration was prepared from a ripe Louzier cane in Mauritius. For generations this cane has been responsible for a very large proportion of the world's supply of cane sugar, and it combines the characteristics of heavy tonnage, sweet and pure juice, and low fibre, which is of such mechanical structure that it affords a megass of good fuel value. In the Hawaiian Islands under irrigation it has many times given over ten tons of sugar to the acre and purity in the mixed mill juices of over 90. Its great failing is its susceptibility to fungus diseases, which accounts for its partial disappearance from the British West Indies and Mauritius. It is a shallow rooter, and hence not a drought-resisting cane, and does not succeed without the tropics, or in tropical countries at higher elevations.

Harrison and Jenman's description[3] of the Bourbon cane is appended :

Bourbon.—Canes few or several, of average length, girth and length of internodes, sub-erect or trailing, nodes constricted, colour yellowish or green, suffused crimson where sun exposed. Arrows, some well and others badly projected. Panicle arrested or well developed, large and copiously branched and flowered.

Below are collected the names that have been applied to this cane (or canes) ; this list should be read in connection with what has been written above.

Otaheite, Bourbon, Louzier, Portii, Tibboo Leeut, Keni keni, Cuban, Bamboo II., China II., Colony, Lahaina, Singapore.

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* See Note in Appendix.   † See *Coloured Plates*.

The Cheribon Canes.—Wray[6] in 1848 describes four canes as Batavian canes; the yellow violet, the purple violet, the transparent or ribbon cane, and the Tibboo Batavee of the Straits; the first three only are considered in this section.

As will be pointed out later, the yellow violet and the purple violet canes have originated, and repeatedly originate, as bud sports from the ribbon cane.

These canes have been introduced into nearly all cane-growing districts; the purple variety has been especially grown in Java, where it is known as the Cheribon or Black Cheribon, in distinction to the White and Striped Cheribon canes. In the British West Indies the light-coloured variety has been grown extensively under the name of White Transparent, and the purple variety as the Purple Transparent; in Cuba the light-coloured variety has been and is extensively grown under the name of Crystallina; also in Hawaii, where it is known as Rose Bamboo. In Mauritius a generation ago the purple variety there called Belouguet was under extensive cultivation. In Louisiana both the purple and striped varieties form standard canes under the names of Home Purple and Home Ribbon, and in Australia the light and dark-coloured varieties are also grown under the names of Rappoh and Queensland Creole.

In the Java literature the term Cheribon applies almost exclusively to the dark-coloured variety; this cane was established by Gonsalves as the standard cane of Java in the middle of the nineteenth century in the face of great opposition, and many references are to be found describing the great benefits thus due to Gonsalves. Though this cane was the one which eventually succumbed to 'sereh' and is now largely replaced by seedlings, it has been the female parent of many of the best of the later varieties.

The light-coloured variety shown in *Fig. 10*,* is of rather less diameter than the Otaheite cane, and is peculiar in having no distinctive colour, but being very susceptible to environment; Wray's term of yellow violet well expresses its colour, and at various stages of growth, yellow, violet, pink and grey shades of colour appear; the leaves are of a darker shade of green.

The dark-coloured variety, *Fig. 11*,* is of a purple colour and of slender habit; the internodes are long in proportion to girth, and the foliage of a lighter shade of green.

The striped variety, *Fig. 12*,* which it is possible to confuse with the Striped Tanna, is of similar proportions to the light and dark varieties; it is striped yellow and blood red, the yellow portions having a polished appearance, whence the term '*Transparent*.' All three of these canes are characterized by a longitudinal channel running upwards from the eye.

The identity of the Cheribon and Transparent canes of the West Indies is made certain beyond reasonable doubt by the following statement due to Krüger.[5] "In Barbados, a little Bourbon is still grown, but the Purple

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* See *Coloured Plates.*

Transparent (probably identical with the Black Cheribon) is chiefly planted, then the Ribbon Transparent and the White Transparent" (which are presumably the Striped Cheribon and the White Cheribon).

In the Java literature relating to cane tests, the cane 'Striped Preanger' is frequently mentioned; in a discussion at the Sugar Congress, at Soerabaya, in 1900, it was stated that the Black Cheribon or Gonsalves cane was at an early date introduced from the Cheribon district to the Preanger district. Under the conditions there the stock grew into the striped form, which was then selected by the planters; hence this cane is probably none other than the original Transparent of Wray, Red Ribbon, &c.

As sugar producers, these canes are of equal importance with the Otaheite. Compared with this cane they are not such heavy croppers under tropical conditions, but are especially suited for colder districts, owing to their habit of early maturity. This is especially true of the striped and dark-coloured varieties, and in Louisiana Stubbs has observed a tendency for the striped cane to pass eventually into the self-coloured dark variety, the dark variety being more adapted to the comparatively cool climate. All of the varieties are of a 'hardy' nature and afford renumerative crops on soils where the more delicate Otaheite will fail, and also under less careful cultivation; though not immune to disease they are less susceptible than the Otaheite, and when grown in Demerara the light-coloured variety afforded a megass of such mechanical structure that it was difficultly combustible.

To these varieties a large number of names have been applied, which are collected below:—

Light Coloured Variety.—La Pice, Le Sassier, Panachee, Rose Bamboo, Mexican Bamboo, White Transparent, Naga B, Blue, Hope, Light Java, Mont Blanc, Rappoh, Crystallina, Tibboo Mird, Green, Mamuri, Yellow Singapore, White Cheribon, Burke.

Dark Coloured Variety.—Louisiana Purple, Black Java, Purple Transparent, Black Cheribon, Tibboo Etam, Purple Violet, Belouguet, Tabor Numa, Queensland Creole, Purple Mauritius, Purple Bamboo, Moore's Purple, Dark Coloured Bamboo, Meera, Gonzalves, Diard.

Striped Variety.—Transparent, Striped Mexican, Striped Louisiana, San Salvador, Seete, Striped Bamboo, Red Ribbon, Striped Cheribon, Home Ribbon, Mauritius Ribbon, Diard rayée, Striped Preanger.

The following irregularities in nomenclature may be noted in connection with these canes :—

1. The purple variety is termed Otaheite cane in Bourbon.

2. The term Bourbon is applied to the light-coloured variety in the collection at Audubon Park.

3. In Jamaica the light-coloured variety is, according to Cousins[9], the Otaheite cane.

4. Stubbs states that the striped variety came originally from Tahiti, and is generally known as the Otaheite Ribbon cane (see Tanna cane).

5. In Demerara a cane introduced under the name Meera is identical with the Purple variety; the term Meera in Malay means red, and is applied to any red cane; the Tibboo Meera of Soltwedel is entirely distinct from this cane.

6. The term Rappoh is apparently an East Indian word applied to a number of canes; the Tibboo Rappoh of Soltwedel is a cane of a greenish-brown colour with a well marked bluish-white layer of wax at the node; canes of the name Rappoh Kiang, Rappoh Maeda, Rappoh Koenig, and White Rappoh also are known.

7. In Queensland the term Cheribon is applied to the Cavengerie cane[10] (see below).

8. The name Seete is given by Fawcett and by Dahl & Arendrup[11] to a greenish-yellow or white cane.

9. The term Crystalline has also been given to the Salangore cane.

10. The Teboe Soerat Mauritius of Soltwedel is an entirely distinct cane.

Harrison & Jenman's[3] description of these canes under the names White Transparent, Purple Transparent, and Red Ribbon, is appended :—

White Transparent.—Canes several, erect and partly trailing, of full average length, barely of full average girth, nodes superficial, internodes of full or over average length, colour at first pink, finally a grey horn tinge in the lower part, and yellow tinged with pink in the upper half, rarely blotched with carmine where sun exposed. Arrows projected well aloft. Panicles full size, copiously branched and flowered.

Purple Transparent.—Canes several or many, full average length, barely average girth, full or over average length of internodes, nodes superficial, cane and internodes very straight, colour at first purplish, finally claret and stone grey. Arrows high projected. Panicles large, copiously branched and flowered.

Red Ribbon.—Canes several, erect, or with some trailing, of full average length, barely of full average girth, long internodes and superficial nodes, colour in part pink and greyish, in part striped pink and claret and yellow. Arrows projected well aloft. Panicles full sized, copiously branched and flowered.

Tanna Canes.—In Mauritius at the beginning of the twentieth century, three canes, known as the Striped Tanna, White Tanna, and Black Tanna, were in extensive cultivation. The two latter were known to frequently originate from the striped variety precisely as the white and black Cheribon canes originate from the striped variety. The following identities may be given from the writer's personal experience and from his correspondence with others familiar with the sugar cane.

Striped Tanna = Big Ribbon = Guingham = Maillard.

White Tanna = Yellow Caledonia = Malabar.

Of the Black Tanna no synonyms, as far as the writer is aware, exist.

The Striped Tanna is beyond any reasonable doubt the cane described by Wray as the Otaheite Ribbon, and which he particularly distinguishes from the ' Ribbon Cane of Batavia' (Striped Cheribon). The latter he states is smaller than the Otaheite Ribbon, and is striped blood-red on a transparent straw-coloured ground, compared with the broad purple stripes on a greenish-yellow ground. In addition Delteil[12] states that the Otaheite Ribbon of Wray is synonymous with the Guingham and Maillard. A cane mentioned by Wray[6] as peculiar to the island of Tanna, and identified by him with the Tibboo teelor, or egg cane, is described in terms applicable to the White Tanna. He remarks on its extreme cleanness, or absence of *cane-itch*, habit of shedding its dry leaves, brittle nature and large eyes; he however mentions that this cane has a habit of bulging between the nodes, a characteristic which is not usually found in the White Tanna.

Of these three canes the light self-coloured variety is by far the most important; at the time of writing, under the name of Yellow Calendonia, it forms the bulk of the cultivation on the unirrigated estates in the Hawaiian Islands; as Malabar, it is the favourite cane of Fiji, and as White Tanna covers extensive areas in Mauritius. All three of the Tanna canes are also cultivated in Australia on the large scale, on the Clarence River the striped variety being incorrectly known as Daniel Dupont.

The striped variety is distinctly short-jointed in proportion to girth, a character which is less pronounced in the white and black varieties; all contain more fibre than does the Otaheite cane; in Hawaii, when grown under the same conditions, the Yellow Caledonia cane will contain 13 per cent. fibre when the Lahaina contains 12 per cent., and the percentage of sugar is in a reverse ratio. They all possess a hard rind, and are thus protected to some extent against the attacks of insects, and are so to be considered comparatively immune to fungus diseases. The megass afforded by them is of such a mechanical structure that it offers a serviceable fuel, but their hard nature offers considerable resistance to milling, and makes a crusher or other preparatory appliance a necessity; generally speaking they are deep rooters, and suffer only to a limited extent from the effects of drought. These three canes are shown in *Figs. 13, 14, 15.** The White Tanna is represented as of a reddish tint; this coloration is very pronounced at certain stages of its growth, while at others the colour is yellow.

In parts of Australia the name Daniel Dupont is applied to the Striped Tanna ; an imported cane of this name at the H.S.P.A. Experiment Station is

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* See *Coloured Plates.*

green with red streaks rather than stripes and remarkable for the intense whiteness of its ground tissue.

In my earlier work, " Sugar and the Sugar Cane," I stated that the Black Tanna was the same as the Tibbo Etam or Black Java, and that the Striped Tanna was the Cheribon cane. This very serious mis-statement I now know to be an error ; it was made on the verbal information of a Java resident of several years' standing. On the same authority I said that Tanna was the Javanese term for '*rich earth*,' whence was derived the name of these canes ; the term Tanna in this case actually refers to the island of that name in the South Pacific ; '*tanah*' is, however, a Javanese word roughly equivalent to '*clay*.'

The Salangore Cane.—Wray[6] describes this cane as, in his opinion, the finest in the world. He mentions that it is remarkable for an excessive quantity of cane itch ; that the leaves when dry are peculiarly adherent, and comments on the large amount of cane wax on the stem, whence have arisen the Malay terms Tibboo biltong berabou and Tibboo cappor.

Wray's opinion has not been supported by other planters, and the following remark due to Harrison[13] aptly describes this cane : —

" Some of us will doubtless recollect the time when Mr. A. would plant a few acres of Salangore cane in the hopes of getting better field returns, and richer cane juice ; how these Salangores in some years flourished and raised hopes of heavy returns of sugar, how in others they unaccountably languished ; but how, whether they flourished or languished, one thing invariably characterized them—miserably poor juice and consequent loss of money."

In the literature of sugar cane expressions of opinion leading to similar conclusions can be found, the cane being sometimes condemned, and at other times referred to in extravagant terms ; it is so well characterized however that there seems to be no possibility of doubt as to its identity, and the conclusion is reached that it is a variety particularly susceptible to obscure local conditions. This cane at the time of writing does not seem to be under extensive cultivation ; it is apparently grown to some extent in Porto Rico and Brazil, and is again being cultivated in Demerara under the name of Green Transparent. In Spanish writings dealing with the sugar cane a variety is referred to as Canne Rocha, or Waxy cane, which in certain references would appear to be this cane. Harrison and Jenman[3] thus describe this cane as it appears in the Georgetown Botanical Gardens :—

Salangore.—Canes numerous, erect, rather under average height, of nearly average girth, much under average length of internodes, nodes slightly contracted, colour whitish or greyish, suffused often with a grey hue, and touched with carmine where sun-exposed. (Rarely arrows.) Panicles large, copiously bunched and flowered, and well projected.

In addition to the native Malay terms of Tibboo biltong berabou and Tibboo capper given by Wray, Delteil gives Pinang and Chinese (in Bourbon) as synonyms, and Harrison and Jenman give the name White Mauritius (in Demerara), and the term *chalk cane* is also met with.

In the literature of the cane the name Crystallina can occasionally be found applied to the Salangore, and the use of this term has led to identification with White Cheribon.

Purdie[14] in Trinidad termed two unnamed varieties, Green Salangore and Violet Salangore ; his description of the former is broadly applicable to the White Tanna.

The Cavangerie Cane. — This cane, which must be included amongst the world's standard varieties, is also known under the names of Altamattie, Po-a-ole, and Port Mackay, under which name it has been extensively cultivated in Mauritius.

It is a claret-coloured cane with an inconspicuous yet clearly defined bronze-green, almost black, stripe, and possesses the peculiarity of not infrequently growing variegated or albino leaves.

It is a cane that affords a juice less pure and sweet than that given by the above discussed varieties, but, being of a 'hardy' nature, and adapted to colder temperatures, is successfully cultivated in the less tropical cane-growing districts, and at higher elevations in the more tropical ones. It has been most extensively grown in Mauritius, in Brazil, and in Australia.

In Australia this cane is called Cheribon.

In Brazil the name Louzier has been applied to this cane.

The name Port Mackay in Java is given to a totally distinct cane, and described by Krüger[7] as a yellow-green cane with very handsome prominent brown blotches where sun-exposed.

Harrison and Jenman[3] thus describe this cane :—

Po-a-ole.—Canes several or numerous, of full average height, girth and length of internodes, nodes superficial, colour light reddish claret. Arrows high projected. Panicles large and copiously branched, very plentifully flowered.

This cane under the name of Port Mackay is shown in *Fig. 17.**

Bamboo Canes.—The term *Bamboo* has been applied to a large number of totally distinct varieties. The Striped Bamboo is a synonym of the striped Cheribon cane, and hence have probably arisen the names of Rose Bamboo and Purple Bamboo applied to the light and dark coloured sports from the striped variety.

Bamboo II. is given by Harrison and Jenman[3] as a synonym of the Otaheite, and Bamboo I. and III. as identical with another yellow cane known as Meligeli or Demerara.

In the Hawaiian Islands a cane successful at high elevations passes under the name of Yellow Bamboo. This cane is alleged to be a 'graft.' It is a rather small yellow cane with a narrow rich green leaf, the sheath of which is thickly covered with prickles ; the internodes are slightly convex, and the eye

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* See *Coloured Plates.*

is small and round. According to priority in the literature of the cane, the term Bamboo should be applied to the Kulloa, Kullore, or Culleroah cane of India. Porter[15] describes it as a light-coloured cane growing to a great height, and to be found on swampy land. Delteil[12] describes it as of a yellow, pale green, and pink colour, Stubbs in addition calling attention to its enlarged nodes and prominent eyes.

Bois Rouge.—This cane is under a limited cultivation in Mauritius: it is an olive green cane heavily blotched with red; it is of slender and erect habit, with long slightly concave internodes.

Settlers.—This cane has been introduced to Australia from Mauritius: it is a dull green thin erect cane with medium internodes; the rind has a tendency to crack: the eyes are prominent and pointed.

Tip Canes.*—Two canes successful at higher elevations in the Hawaiian Islands are known as the Striped Tip and the Yellow Tip canes, the latter being a sport from the former.

The striped variety is a small thickly stooling cane, striped dark red and pinkish green, changing at maturity to yellowish-red and yellow. The sheaths of the young leaves have light purplish margins, and are covered with long prickles which rub off easily, and disappear as the leaf dries. The eye is large, long and pointed; nodes prominent, internodes concave; the internode is channeled from the eye upwards.

The self-coloured variety is a light green cane, turning yellow at maturity; it resembles the striped variety, except that the prickles on the sheath are fewer, and the purplish margin on the leaf sheath is absent. This cane is referred to in some of the publications of the Hawaiian Sugar Planters' Station as 'Unknown.'

Uba.*—This cane is at the time of writing cultivated with success in Madeira and Natal; that is to say, in extra tropical countries. It is stated by John Dymond[16] to be identical with the Zwinga or Japanese cane described by Stubbs[2], who states that it is extremely hardy, enormously productive under good cultivation, extremely woody, and of moderate sugar content.

The Elephant Cane.—The true Elephant cane originates from Cochin China; it is relatively an enormous cane, and is allowed to grow undisturbed for a period of years as an ornamental plant; it may in five or six years reach a height of 30 feet. It is of absolutely no importance as a sugar producer. The Elephant cane is figured by Soltwedel[4] under the name Teboe Gadjah; as shown by him it is of a very dark greenish-grey, almost black colour irregularly blotched with greenish-yellow patches

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* See Note in Appendix.

FIG. 10.
ROSE
BAMBOO.

3
4
SIZE

PLATE II

The Creole Cane.—This term occurs frequently in the literature and its history is apparently as follows. The Crusaders brought to Southern Europe a cane from the Orient; this cane was cultivated in Sicily, Southern Spain, the Canaries, Madeira and eventually reached the New World about 1500; later when the South Pacific types were introduced, it was necessary to name this cane, when by reason of its already long association with the colonies it was called ' *Creole*.' It is a small yellow cane probably of Indian origin, and may perhaps be included amongst the Indian canes described in a separate section.

Red Canes.—Wray[6] describes a certain cane under the name of Red Cane of Assam, and states that the native name is Tiboo Meerah. Krüger[7] mentions two canes to which this term is applied; Tiboo Meerah, and Tibboo Meerah Borneo. The Tibboo Meerah figured by Soltwedel[4] is a dirty claret-coloured cane, merging into purple on the older internodes, and this is, the writer understands, the cane referred to under that name in the literature of the sugar cane as it refers to Australia. Harrison and Jenman[3] give Meerah as a synonym of the Purple Transparent, but the Tibboo Meerah of Soltwedel is quite distinct from the Purple Transparent or Black Cheribon.

Horne.—This cane is of great interest, as it is one of the earliest, if not the earliest, recorded instances of a striped cane originating from self-coloured cane. This observation is due to Mr. John Horne, at one time Director of Forests and Gardens in Mauritius; the cane from which it originated was a Louzier cane, and in Mauritius, where it is cultivated on the estate scale, it is indifferently known as Louzier rayée; the writer has also observed occasionally a cane exactly similar to the Horne appearing in Bourbon fields in Demerara. The cane is very irregularly striped in red, green, and yellow colours.

The Green Rose Ribbon.—This cane, which has been cultivated with success in Australia, is a sport from the Otaheite, which it resembles in habit; it is striped green and a yellowish pink colour. It is also known as Green Ribbon, Brisbane, Malay, White Striped Bourbon, and in Mauritius as Louzier rayée.

The Iscambine Canes.—Among canes introduced into Mauritius from New Caledonia was a striped cane originally known as Tsimbec; this cane is striped yellow and red, and from it has sported a cane known as Iscambine rouge, represented in *Fig. 18.** Both these canes are found on the estate scale in Mauritius; they are soft canes with a brownish-yellow ground tissue; they are subject to variation and a number of Iscambines are known.

Indian Canes.—S. M. Hadi[17] divides the canes of the United Provinces into Ukh, Ganna, and Paunda canes. The Ukh canes are small

* See *Coloured Plates*.

thin and reed-like with small and narrow leaves; the internodes are short, the eyes small and depressed, and many varieties have a well-defined central fistula in the stalk. The Paunda canes are the acclimatized canes admittedly of introduced origin and under native names include many of the varieties already described. The Ganna canes seem to be intermediate between the Ukh and Paunda types. Mollison and Leather[18] have proposed a classification of Indian canes under five heads; their A class seems to correspond with Hadi's Ganna and Paunda canes, their B, D, and E classes apparently including the Ukh canes.

The classification of the canes of India seems to be a hopeless task, especially when the numerous dialects and races of the Peninsular are remembered; in the forties many varieties were introduced from Mauritius and these have received local native names, adding still more to the difficulty of classification. In addition to those mentioned above, the following may be referred to :—

Restali.—In Madras, a striped cane, perhaps the striped Cheribon.

Nanal.—In Madras, refers generally to a reed-like cane.

Chunnee.—An Indian cane which Kobus has used as the male parent of his hybrids, the female being the Cheribon.

Samsara.—A white cane introduced (but unsuccessfully) into the West Indies.

Kullore.—A white cane and one to which the term *bamboo* seems to have been earliest applied.

Javanese Canes.—Soltwedel[4] figures and describes a large number of canes occurring in Java; attention has already been directed to the Cheribon, Loethers, Meera, and Rappoe canes. Two canes illustrated by Soltwedel as Tibboo Soerat Mauritius and Branchu blanche the writer recognises as very similar to the Branchu rayée of Mauritius and the Cavangerie respectively; the Branchu blanche is a self-coloured sport from the Branchu rayée, both of which were once largely grown in Mauritius. It may be here mentioned that in the Malayan Orient the term *Soerat* applies to any striped cane and not to one particular cane.

Other canes mentioned in the Java literature are the Muntôk, introduced from Banca, immune to sereh but subject to red rot of the stem, and of inferior sugar content and purity to the Cheribon; the Fiji or Canne Morte, immune to sereh, and a parent of several valuable seedling varieties; the Bourbon, a purple cane, and hence quite distinct from the West Indian Bourbon; the White, Red, and Black Manila canes, all characterized by swollen nodes, the last of which is apparently under somewhat extended cultivation.

34

New Guinea Canes.—Of late years canes have been introduced from New Guinea to Queensland. The following descriptions are due to Maxwell[19] :—

N. G. 8a, or Gogari.—Dull, deep green cane, of moderately stout habit, turning red on exposure ; internodes 4-6 inches ; occasionally grooved, flesh yellow.

N. G. 15, or Badilla.—A dark purple to black cane, stout, with white waxy rings at the nodes, internodes 2-3 inches, often longer in ratoons, of erect habit, foliage somewhat erect, very green and in young cane often of a reddish tinge, flesh white, of high sugar content, often weighs up to 1 lb. per foot.

N. G. 24 or Goru or Goru possi possana.—A moderately stout greenish brown to copper coloured cane, joints zigzag, internodes 3-4 inches, slight waxy bloom, basal end develops roots, upper eyes sometimes shoot, foliage broad and plentiful, flesh yellow.

N. G. 24a or Goru scela scelana.—Like N. G. 24 but striped with red, moderately stout, internodes 3-4 inches, foliage broad and plentiful, flesh yellow.

N. G. 24b or Goru bunu bunana.—Like N. G. 24 in shape but of a yellow to yellowish green colour, sometimes marked on exposure with reddish granular spots, internodes 3-4 inches, eyes full and prominent, foliage broad and plentiful, flesh yellow.

N. G. 64.—A brownish to olive cane striped with claret, with small linear skin cracks, moderately stout, internodes 3-5 inches, contracted at nodes and bulging towards centre, foliage red to purple when young, flesh white.

Pacific Islands Canes.—The following canes have been described by Cuzent[20] under native names ; the botanical names given afford the impression that they are distinct species, while actually they are only varieties of the species *Saccharum officinarum*.

To uti. S. atrorubens.—Stalk and pith violet, imported from Java by Bougainville in 1782.

Rurutu. S. rubicundum.—Stalk and leaves violet, pith white.

Irimotu. S. fragile.—Stalk green and brittle, pith white, numerous hairs.

To oura.—Violet and yellow striped cane.

Piaverae. S. obscurum.—Stated to be the Creole cane.

To avae. S. fragile var.—Green and yellow striped cane.

Vaihi or Uouo. S. glaber.—A white cane introduced from the Hawaiian Islands. Melmoth Hall thinks it possible that the Vaihi is the Otaheite of the West Indies ; this is improbable in the light of what has already been written on the origin of the Otaheite cane ; the Vaihi may be one of the white indigenous canes of Hawaii such as *Ko Kea*. The same writer also thinks that the *To oura* is the purple striped Otaheite cane of Wray, or the *Guingham* of Mauritius, *i.e*, *Striped Tanna*.

Hawaiian Canes.—The native canes of these islands have been described by C. N. Spencer[21] as under :—

Ko Kea.—A greenish-white cane, not unlike the Otaheite, and the one most commonly grown before the introduction of the latter.

Ainakea.—A green and red striped cane, which Stubbs, quoting from a letter, says was brought from Mauritius; where it is known, he says, as the light striped Bourbon; this latter cane, though similar, is within the writer's knowledge distinct.

Oliana.—A yellow very woody cane.

Papaa.—A purple cane.

Palania.—A purple cane.

Hillebrand, in the *Flora Hawaiiensis*, gives the *Puaole* (= *Cavengerie*) as indigenous to Hawaii, but it was probably introduced from the South Pacific.

Brazilian Canes.—The canes common in Brazil are described by Sawyer.[22]

The *Cayanna Antiga* is evidently the Otaheite cane (or canes).

The *Black cane* is believed by Sawyer to be the Cheribon cane, but its description more approaches (in the writer's opinion) to the Black Tanna.

The *Imperial* is a green and yellow striped cane.

The *Manteiga, Envernizada, Calvacante, Flor de Cuba, San Pello,* are names applied to a butter-coloured cane.

The *Aleijada*, a seedling cane destitute of hairs, with one or more abortive internodes on every stalk.

The *Crystallina*, the description of which fits the White Transparent, &c.

The *Roxa Louzier*, introduced from Mauritius.

The *Salangore*, the description of which fits that of this cane already given.

The *Cinzenta* or *Grossona*, similar to the Salangore when young, and at maturity approaching the Cayanna Antiga, and referred to as being of merit.

The *Ferrea* or *Cavengerie*, a bright purple cane, and hence distinct from the Cavengerie already described.

The *Bois rouge* or *Vermelha*, introduced from Mauritius, and of a ruby-red colour, regarded as an inferior variety.

The *Bronzeada* or *Roxinha*, resembling the Crystallina when young, and the Antiga at maturity.

The *Cayanninha*, much resembling the Antiga.

Sports.—By the term 'Sport' is meant a plant which in some way is notably different from its parent, and whence it originates '*per saltum*'; with the cane, sports originate by bud variation, and in view of the evidence collected below it is established beyond reasonable doubt that certain of the more valuable cultivated varieties have so originated. The earliest recorded

instance of bud variation is due to J. F. Horne[23] who, in describing canes imported into Mauritius, writes :—" On examining the plants of this cane at Mon Plaisir, a plant was noticed giving green, instead of striped, canes. On further examination two other plants were found, one of which, while producing striped canes from one eye, produced green canes from another eye, both of which eyes belonged to the same piece of cane, while the second plant produced both striped and green canes from one and the same eye."

A very similar observation was made by Melmoth Hall[24] a little later, who writes :—" I have in one instance seen no less than three distinct canes springing from one stool of the ribbon variety, one entirely yellow, one entirely green, the other being the usual ribbon cane ; while from other stools in the same field I found canes either of a uniform green, purple or purplish brown ; all the rest spring from the same ribbon cane root, being striped in the usual way."

A manuscript communication to the writer from M. Auguste Villele, of Mauritius, ascribes the origin of the Louzier cane of that island to a sport from a striped cane known as Mignonne, imported from New Caledonia ; this sport was observed by a M. Louzier. In the early nineties the Striped Tanna canes were brought to Mauritius, and these were observed frequently to throw sports, whence have come the White and Black Tanna canes. Other instances are recorded in the West Indies where the Red Ribbon (*cp. supra* under Cheribon canes) is known to give self-coloured canes identical with the Burke, and J. F. Clark,[25] of Queensland, has recorded that the Striped Singapore cane there throws sports which are apparently identical with the Rappoe. The Red Ribbon and Striped Singapore canes are synonomous, as are also the Burke and Rappoe varieties.

It has been shown above that the White and Black Cheribon canes have been and are extensively cultivated, and there seems no reason to doubt that they originated as sports from a ribbon cane ; in no other way is it possible to account for the terms White, Black, and Striped Cheribon ; Transparent, White and Purple Transparent ; Striped Bamboo, Rose Bamboo, and Purple Bamboo ; and it must have been with full knowledge of their origin that these names were given.

Assuming the identity of the Louzier with the Otaheite and Lahaina canes, and remembering the origin of the former, it is also probable that the latter originated in the same way, but having been introduced at early dates as self-coloured canes no suspicion of their origin arose. This cane also is known to throw a striped sport indistinguishable from the Mignonne from which the Louzier arose, and this cane when planted separately throws self-coloured sports, so that here a complete cycle through striped cane, self-coloured cane, striped cane exists, though it is impossible to state which was the original type ; perhaps the explanation of the phenomenon is to be found in a cross-fertilization of the original cane.

It is important to note that when a striped cane throws sports two varieties arise, one light-coloured and one dark-coloured, and that almost always each light-coloured and each dark-coloured cane is identical; thus, almost every light-coloured sport from a striped Tanna cane is a white Tanna, and almost every dark-coloured cane is a black Tanna.

Sporting from self-coloured canes is a less frequent phenomenon than from striped canes, but evidence exists that some self-coloured canes throw two distinct striped sports. When in Mauritius the writer understood that it was a matter of common knowledge that the Louzier threw two distinct sports, one a cane identical with the Mignonne, and another (described already) called the Horne cane after its first observer: both these canes are in Mauritius indifferently known as Louzier rayée. The writer has also observed these sports springing from the Otaheite cane under the name of Bourbon or Lahaina in Demerara and in Hawaii.

Another instance of a striped cane springing from a self-coloured cane was observed in the Hawaiian Islands by Mr. E. W. Broadbent, who found a green and yellow ribbon cane springing from the Yellow Caledonia (White Tanna). In this case the sport was quite distinct from the Striped Tanna, the parent of the White Tanna.

In Mauritius the Port Mackay (Cavangerie) is known to give a black cane, the Port Mackay Noir, and the Striped Iscambine imported thither from New Caledonia has given rise to several Iscambine canes, one of which is of merit.

Finally, in Hawaii, a cane—the Striped Tip—of uncertain origin, has afforded the Yellow Tip, also a cane of merit.

Seedling Canes.—Previous to 1885 it was generally believed that the cane was infertile. This belief may perhaps be traced to the statement made by Hughes in 1750, in *The Natural History of Barbados;* the contrary statements of the eighteenth century travellers, Rumphius and Bruce, being too vague to be of value. Notwithstanding the fruit of the cane had been accurately described by Dutrone in 1790, and figured in Porter's treatise (1843). In 1859, Parris, in a letter in the *Barbados Advocate,* stated that he had observed cane seedlings, a statement again confirmed by Drumm in the Barbados *Agricultural Reporter* in 1869, the letter announcing the observation being copied in the *Produce Markets' Review.* In addition, about this time, seedlings were tried on the large scale in Barbados, but, unfavourable characters being developed, their cultivation was abandoned. At this same time the Baron de Villa Franca in Brazil wrote as if the fertility of the cane was without question, and was a fact of common knowledge. The rediscovery of this very important fact was made independently, and nearly simultaneously, by Soltwedel in Java, in 1888, and by Harrison and Bovell in Barbados, in 1889. Since then many valuable varieties have been raised. The pioneer and chief workers in this field have been Went, Wakker, Kobus, Bouricius and

Moquette in Java, Harrison, Bovell, Jenman, Hart and Lewton-Brain in the British West Indies, the brothers Littée in Martinique, Bonâme and Perromat in Mauritius, and Eckart in Hawaii; in addition, private enterprise is exemplified by the raising of seedlings at the Diamond Plantation in Demerara, and at the Hambledon Mill in Australia; it has also been undertaken by many planters in Barbados, in Mauritius, and in Brazil.

At first, in Java, this discovery was regarded as of academic interest only, since it was believed that the Cheribon cane had reached commercial perfection, and it was not till the appearance of the sereh disease that the propagation of seedlings was undertaken with vigour; a similar lack of incentive was never present in the British West Indies, and the discovery was followed up by Harrison and his colleagues from the first.

The factors governing the properties of seedling canes have been studied in great detail by Harrison and Jenman[26] and by Went and Prinsen Geerligs[27]. Briefly it appears from their work that the cane is enormously subject to variation and that there is but little tendency towards the inheritance of the properties of either parent; in all cases where successful seedlings have been obtained it has been by growing a very large number of seedlings and eliminating almost all. Harrison has pursued this method up to the extent of raising over 1,000,000 seedlings, the very greater proportion of which were destroyed off hand; of the remainder only a few survived the first preliminary selection, and eventually these were cut down to very small numbers. In Java, also, very large numbers have been raised and have been rapidly weeded out at an early stage of growth.

It was observed at an early stage that the Cheribon cane in Java had no fertile pollen whilst the ovaries of the flower were normal; hence the plan of growing in alternate rows a pollen-bearing variety and the Cheribon cane arose; most of the Javanese seedlings have been thus obtained. The most prolific workers in Java have been Bouricius who used the Canne Morte, and Kobus who used the Chunnee (an Indian variety), as the male parents. Elsewhere the seedlings raised have generally been adventitious, the male parent being uncertain.

In 1904 Lewton-Brain[28] in Barbados and Mitchell[29] in Queensland emasculated cane flowers and fertilized them with pollen from another variety, thus obtaining hybrids of certain parentage; this method is now being followed up, but the skill required and the small number of hybrids obtained, and there being at present no reason for supposing that these hybrids will develop superior qualities over adventitious seedlings, makes it doubtful if this method is advisable. At the very least it can be said that very valuable canes have resulted from the scheme of selection from a very large number of seedlings, a method which is simplified by the observation that it is only the outstanding canes of merit grown under experiment station conditions that have any chance of success on the estate scale.

Of the seedling canes that have become prominent there may be mentioned—

Demerara Canes.—Referred to under the initial D.

D. 74.—*Stalk:* Pale green, erect, stout, medium length of joint. *Leaf:* Broad, light green. Arrows profusely and matures early.

D. 95.—*Stalk:* Dark purple, erect, average girth and length of joint. *Eyes:* Prominent and inclined to sprout. *Leaf:* Light green, narrow, erect. Arrows profusely and matures early.

The above two canes are historical, as they were the two first sent out by Harrison. In Demerara they have proved of no merit, but their habit of early maturity has made them canes of value in Louisiana.

D. 78.—*Stalk:* Greenish red, erect. *Leaf:* Dark green. Arrows sparsely.

D. 109.—*Stalk:* Dark purple, erect. *Leaf:* Dark green, narrow. This cane possesses in a marked degree the property of ' going back '—that is to say, it is very atavistic—and in second and third ratoons degenerates into a reed-like growth.

D. 145.—*Stalk:* Greenish purple, erect, stout, very brittle. *Eyes:* prominent. Arrows sparsely.

D. 625.—*Stalk:* Erect, yellow, stout. *Leaf:* Light green. *Eyes:* Small. One of the most successful of the Demerara canes.

D. 1135.—*Stalk:* Erect, red, of small girth. *Leaf:* Light green. *Eyes:* Prominent. Very large number of canes in a stool. This cane is not largely grown in Demerara, but on introduction to Hawaii has shown signs of being of great merit.

Barbados Canes.—Referred to by the initial B.

B. 109.—*Stalk:* Erect, yellowish green, stout, joints of average length. *Leaf:* Dark green, separating easily from the stalk when dry. Arrows sparsely.

B. 147.—*Stalk:* Yellow, recumbent, average girth and very long jointed, with a well marked channel. *Leaf:* Broad, dark green, adherent. Arrows sparsely.

This cane when first established received much ill-advised advertisement, and though of great merit has consequently suffered by comparison.

B. 208.—*Stalk:* Erect, green, with peculiar swellings at many nodes. *Leaf:* Vertical, dark green. *Eye:* Prominent, inclining to sprout. This cane is extraordinarily subject to environment, in some places being of great merit and in others valueless; it is unsuited for heavy clays, is of great saccharine strength and is reputed to be drought-resisting; it is also subject to variation.

B. 306.—*Stalk:* Erect, yellow, long jointed. *Leaf:* Broad, dark green, separating readily. *Eye:* Small. Arrows sparsely.

Mauritius Canes.—Referred to by the initial M. The following notes were collected during the writer's residence in this island where systematized work has been absent.

M. 33. A green recumbent cane, with some peculiar abortive joints; medium girth, long internodes.

M. 53. A dark purple, medium-sized cane.

M. 80. A reddish-purple stout cane.

M. 131. A small upright purple cane, extremely prolific in number of canes to a stool.

Java Canes.—Of the very many canes raised in Java, the most prominent are described below; of these P.O.J. 100. is a cross between a black Borneo cane and an unknown father; Bouricius 247 is a cross between the Canne Morte or Red Fiji (male) and the Cheribon (female); these were obtained by Wakker and Bouricius. The others were obtained by Kobus from crossing Cheribon canes with Chunnee, and to him I am indebted for the descriptions below.

33 P.O.J.*—(1.) Dark violet, brown red when older; (2.) Thick all over the internodes; (3.) Constricted; (4.) Straight line; (5.) Spherical, small, not prominent; (6.) Invisible; (7.) 2-3; (8.) White; (9.) Green, pink where sun-exposed; (10.) None; (11.) Green; (12.) Narrow, upright, not bending; (13.) Strongly lobed at one side, slightly lobed at the other side; (14.) An upright, long, strong cane, does not arrow, immune to sereh.

36 P.O.J.—(1) Green; (2.) Fairly thick all over the internodes; (3.) Somewhat constricted; (4.) A straight line; (5.) Cordiform; (6.) Invisible; (7.) 2-3; (8.) White; (9.) Green, pale pink where sun-exposed; (10.) None; (11.) Green; (12.) Narrow, long, bending near top; (13.) Slightly lobed on one side; (14.) A long hard and strong cane, arrows sparsely ♀ and ♂ sterile; immune to sereh.

100 P.O.J.—(1.) Golden to light brown with fiery red sunburnt patches; (2.) In a ring under the nodes; (3.) Cylindrical; (4.) Faintly zigzag; (5.) Oval when young, somewhat swollen or prominent later; (6.) Distinct on two-thirds of the internodes; (7.) 3-4; (8.) White; (9.) Green, pink where sun-exposed; (10.) Dense thick hairs on back and sides; (11.) Yellowish-green; (12.) Broad, not very long, bending near top; (13.) Slightly lobed at one side; (14.) An upright, rather short cane, very sweet, ripens early, arrows profusely, ♀ fertile, ♂ sterile, nearly immune to sereh.

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*(1.) Colour; (2.) Wax; (3.) Shape of internode.; (4.) Arrangement of internodes; (5.) Shape of eye; (6.) Channel above eye; (7.) Rows of roots; (8.) Colour of pith; (9.) Colour of leaf sheath; (10.) Pilosity of sheath; (11.) Colour of leaf blade; (12.) Shape of leaf blade; (13.) At junction of sheath and blade, the former is.... ; (14.) General characters.

139 P.O.J.—(1.) Pink when young, dirty greenish pink when older; (2.) Fairly thick all over the internodes; (3.) Cylindrical; (4.) Faintly zig-zag; (5.) Small, spherical; (6.) Distinct on two-thirds of the internodes; (7.) 2-3; (8.) White; (9.) Green, pink where sun-exposed; (10.) None; (11.) Green; (12.) Narrow, long, bending at top; (13.) Lobed on one side; (14.) A short, upright cane, very sweet, ripens early, does not arrow, immune to sereh.

161 P.O.J.—(1.) Pink when young, later yellowish green, mixed with dirty pink; (2.) Thick all over the internodes; (3.) Cylindrical; (4.) Faintly zig-zag; (5.) Cordiform; (6.) Faintly visible over half the internodes; (7) 3-4; (8.) White; (9.) Green; (10.) None; (11.) Green; (12.) Long, narrow, bending near top; (13) Lobed on one side; (14) A long, sweet, upright cane, arrows sparsely, ♀ and ♂ fertile, immune to sereh.

181 P.O.J.—(1) Yellowish red with sunburnt patches of dark red; (2.) Fairly thick all over the internodes; (3.) Somewhat constricted; (4.) Faintly zig-zag; (5.) Cordiform, somewhat pointed and prominent; (6.) Faintly visible on half the internodes; (7.) 3; (8.) White; (9.) Green; (10.) None; (11.) Green; (12.) Very narrow, upright; (13.) Not lobed; (14) A long, upright thin cane, arrows profusely, ♀ and ♂ fertile, immune to sereh.

213 P.O.J.—(1.) Bright violet red; (2.) In a ring under the nodes; (3.) Cylindrical; (4.) A straight line; (5.) Oval, small; (6.) Distinct on two-thirds of the internodes; (7.) 3; (8.) White; (9.) Green, dark pink where sun-exposed; (10.) None; (11.) Green; (12.) Bending at top; (13.) Not lobed; (14.) A long upright thinnish cane, tillering profusely, very sweet, arrows profusely, ♀ fertile, ♂ sterile, immune to sereh.

228 P.O.J.—(i.) Violet red when young, later a dirty brown; (2.) Fairly thick all over the internodes; (3.) Constricted; (4.) A straight line; (5.) Cordiform broad; (6.) Faintly visible on half the internodes; (7.) 3-4; (8.) White; (9.) Green, pale pink where sun-exposed; (10.) None; (11.) Green; (12.) Narrow, long, bending at top; (13.) Strongly lobed at one side; (14.) Tillers profusely, very sweet, arrows moderately. ♀ fertile, ♂ sterile, immune to sereh.

247 Bouricius.—(1.) Dark violet red; (2.) Fairly thick all over the internodes; (3.) Cylindrical; (4.) Distinctly zig-zag; (5.) Cordiform; (6.) Invisible; (7.) 3-4; (8) White; (9.) Green, dark violet where sun-exposed; (10.) Some stiff hairs on back; (11.) Dark green with a violet tint; (12.) Broad and long bending at top; (13.) Not lobed; (14.) An upright, long and thick cane, sweet juice, ripens late, arrows occasionally. ♀ and ♂ fertile, liable to sereh.

Home of the Sugar Cane.—The place whence the cane was introduced has been the subject of speculation and controversy, India and the South Pacific being the places most in dispute. In 1891 Kobus[18] remarked on the differences between the Ukh canes of India and those cultivated in Java; this difference is apparent from Hadi's description of the former, and is so pronounced that it seems fair to suggest that the cultivated varieties of cane (elsewhere than in India) and the Ukh canes are not merely varieties but distinct species.

Of the varieties cultivated elsewhere than in India it is certain that the Otaheite cane (or canes), the Tanna canes, the Cavengerie cane, and the Escambine canes are indigenous to the South Pacific; the Cheribon canes have certainly been known in Java for generations, but the writer has never found any authoritative statement that they are the indigenous. The literature of the cane shows, too, that these Cheribon canes have also been known in the South Pacific from early times, and even the name 'Otaheite' is in some places *(cp. supra)* attached to these canes. In addition, the writer has been authoritatively informed that canes of the Cheribon type were known in India as Otaheite canes at the end of the eighteenth century. There seems, then, much reason to suppose that the Cheribon canes are not indigenous to Java, but originated from the South Pacific; if, as seems reasonable, this speculation connecting these canes with the South Pacific is correct, then all the standard cultivated varieties of cane originated in the South Pacific, that is to say east of Wallace's line, and they form, at the very least, a type of cane very far removed from those found to the West.

The statement that the 'Bourbon' cane came to that island from the Malabar coast is often found; the original statement the writer has never been able to trace, and at the most the statement only implies that the vessel that brought the stock to Bourbon cleared from that locality.

The evidence that the sugar cane is indigenous to the New World seems quite unsatisfactory.

REFERENCES IN CHAPTER IV.

1. *S. C.*, 220.

2. Stubbs' *Sugar Cane*, p. 66.

3. *S. C.*, 273.

4. *Formen und Farben Saccharum officinarum.*

5. *Bull.* 26, *Agric. H.S.P.A.*

6. *The Practical Sugar Planter*, pp. 1-18.

7. *Das Zuckerrohr*, p. 124.

8. *Bull. Assoc. Abs.*, October, 1907.

9. *W. I. B.*, VIII., 1.

10. *The Sugar Journal*, August, 1895.

11. *Sugar*, XII., 1.

12. *Le Canne à Sucre*, pp. 14-18.

13. *S. C.*, 337.

14. *S. C.*, 124.

15. *Nature and Properties of the Sugar Cane*, p. 218.

16. *S. C.*, 206.

17. *The Sugar Industry of the United Provinces of Agra and Oude*, pp. 3-36.

18. *Dictionary of the Economic Products of India*, pp. 938-942.

19. *Report Bur. Exp. Stat., Queensland*, 1907.

20. Quoted in Simmond's *Tropical Agriculturist*.

21. Thrumm's *Hawaiian Annual*, 1882.

22. *Relatorio apresentado a Sociedad Paulista de Agricultura.* S. Paulo, 1905.

23. *S. C.*, 17.

24. *S. C.*, 64.

25. *W. I. B.*, II., 4.

26. *S. C.*, 336, 337.

27. *S. C.*, 310, 311, 321, 322, 323.

28. *W. I. B.*, IV., 6.

29. *Report of Queensland Acclimatization Society*, 1905.

CHAPTER V.

SUGAR CANE SOILS.

The cane is a plant which in its economy demands large quantities of water, and hence when grown under natural conditions it requires a soil of considerable water-retaining power. Such a soil is represented by a typical clay, and such soils under profitable cane cultivation are to be found in British Guiana, Louisiana, and in other countries.

Following on clays, loams and alluvial deposits, containing large quantities of humus which also belong to the water-retaining type, are suited for cane cultivation. Not less important than a high retentive power for water is the necessity for the removal of an excess of water; a clay soil standing on a porous substratum is for this reason much more suitable than one where the under-drainage is less complete. Where ample water is available for irrigation lighter soils of no great water holding capacity give, with intensive fertilization, enormous yields; the estates in Hawaii which have become notorious for their high returns are of this class, and yields but little inferior are obtained in Peru from very light sandy soils.

These last soils under natural conditions are quite unsuited for cane cultivation; in such soils, unless under artificial irrigation, a small cane with a high fibre content is obtained. In soils where the moisture content is too high, whether due to excessive rainfall or to insufficient drainage, the maturity of the cane is delayed, and a product with but a low percentage of sugar is obtained.

Delteil[1] makes the following statement with regard to cane soils :—

"In mellow open soils, watered by rain or irrigation, the cane becomes fine and large and gives much sugar. In light sandy soils, or in volcanic soils of recent origin, the juice is very sweet, but the canes are somewhat small.

"In calcareous soils, the canes develop superlatively well, the juice is rich and easy to work. In alluvial soils, too moist or too rich in alkalis, the canes have a fine appearance, but the juices are poor in sugar, work with difficulty and produce much molasses."

Bonâme[2] makes the following pertinent observations on cane soils and climate :—

"The cane grows more or less well in all soils if it receives the care and manures that its economy demands; but, to develop vigorously, and to supply a juice rich in sugar, it demands a free and deep soil. The physical properties of the soil are at least as important as its chemical composition, and if irrigation is impossible during the dry season its coolness will naturally be one of the principal factors in the production.

"The most favourable nature of soil varies with the climate.

45

"Where rain is abundant the soil should be light and porous; if rains are scanty a too light soil will dry rapidly, and vegetation will be checked; the cane will not completely die, but in place of giving large stalks, rich in sugar, it will produce small, dry, hard and woody stalks. With a relatively dry climate a heavy soil will give good returns if the rains are evenly distributed.

"With a rainfall of 5 to 6 metres (197 to 236 inches) a sandy soil, draining easily, will give an abundant return with a high consumption of manure. A clay soil, especially if it is situated on a plain, will be constantly saturated with stagnant water, which will prevent the aëration of the soil; canes will develop feebly, and their roots will rot little by little, leading to the death of the stalk.

"Some alluvial earths produce a luxuriant vegetation in wet years. The canes are very fine, but very watery.

"Other things being equal, a calcareous clay soil not excessively light will give sweeter canes than a clay containing vegetable débris, but the yield will generally be less abundant. If the rains are sufficient and conveniently divided, returns both for the cultivator and for the manufacturer will be excellent. If the season is wet the advantage will remain with the lighter soils, whilst if it is dry the canes will suffer much and will afford stunted and woody stalks.

"High and almost constant results will be obtained with irrigation and porous soils; for the growth can be regulated at will, and conducted in a fashion so as to obtain the maximum cultural and industrial return, promoting the size of the cane and its leaf development in the first stages of its growth and without intermission, until the time arrives when it is necessary to develop the juices formed at an early stage."

Reynoso[3] says :—

"Experience has shown that lime is a necessary element in the constitution of soils most appropriate to the cane; in calcareous soils not only are the most robust canes grown, but these also afford juices richest in sugar from which is easily extracted the desired product. These soils are both of 'great return and very sacchariferous,' but it must not be forgotten that lime is but one element which, associated with others, forms good soils."

The nature of the soil has a profound and imperfectly understood effect on the sugar cane, considered in its varietal aspect; a variety which succeeds on, say, a heavy clay may be a failure on a sandy soil. This point has been very prominent in connection with the new seedling varieties, so much so that the success of a seedling on one type of soil is no evidence that it will be successful on another, even when climatic conditions are little changed; the seedling B. 208 is a case in point.

Special Points in regard to Cane Soils.—The cane has been accused of being a haliophile plant, and in certain districts, such as British Guiana, and the Straits Settlements, it is grown in soils containing a notable proportion of salt; this point is reflected in some analyses of the cane ash collected in a subsequent Chapter, some of which show large percentages of sodium chloride. This point has been very thoroughly discussed by Geerligs,[4] whose results show that while the cane can grow normally on such soils, it is in no way benefited, and cannot be considered as haliophilous.

Du Beaufret[5] states that in French Guiana cane soils are renovated by periodic floodings with sea water.

Hawaiian Soils.—The soils of the Hawaiian Archipelago have been examined in great detail by Maxwell[6] and by Eckart and to a less extent by Crawley, by Shorey, and by Hilgard;[7] in view of the exceptionally high returns obtained in this district the study of these soils is of especial interest.

The soils of the Hawaiian Islands have been formed by the decomposition of black basaltic lavas containing very large quantities of iron and lime, but much smaller quantities of potash; these basalts also contain considerable quantities of phosphates in the form of apatite.

Maxwell classifies the Hawaiian soils as follows:—

A.—Geological Formation.

1. Dark Red Soils.—Soils formed by the simple weathering of normal lavas, in climatic conditions of great heat and dryness.

2. Yellow and Light Red Soils.—Soils derived from lavas that underwent great alteration, under the action of steam and sulphurous vapours, at the time of, or after, emission from the craters.

3. Sedimentary Soils.—Soils derived from the decomposition of lavas at higher altitudes, and removal and deposition by rainfall at lower levels.

B.—Climatic Classification.

1. Upland Soils.—Soils formed under lower temperatures and greater rainfall, and distinguished by a large content of organic matter and nitrogen, and by a low content of the elements of plant food in an available state; these elements having been removed by rainfall.

2. Lowland Soils.—Soils formed under a high temperature and less rainfall, and characterized by a lower content of organic matter and nitrogen, and by a higher content of the elements of plant food in a state of immediate availability; which is due in part to the receipt of some soluble constituents from the upper lands, and to a smaller rainfall over the lower levels.

It is on the dark red soils and on the sedimentary soils that the high yields of cane in this district are produced. These sedimentary soils are often of great depth, reaching to as much as 30 feet, and form the soil of the most productive areas in the group of islands.

The colour of the yellow soils is due to ferrous salts, and it is to the presence of these bodies that Maxwell attributes the smaller productiveness of these soils. (The yellow colour of the clay known in Demerara as 'Yellow Mary,' the obnoxious nature of which is well known, is also due to ferrous salts.)

The soils of Hawaii are all 'basic' in character, and are consequently marked by a low proportion of silica, in contradistinction to soils as clays of an 'acidic' nature which consist very largely of silica. The quantity of iron in Hawaiian soils is very remarkable, the percentage of ferric oxide reaching to as much as 30 per cent.

As a general rule the soils are 'light' and easily worked, and in every way fitted for the production of enormous crops. The following figures

give the mean composition of the soils of the Hawaiian Islands based on 397 analyses, by the American (United States) official method* : —

Island.	Lime. Per cent.		Potash. Per cent.		Phosphoric Acid. Per cent.		Nitrogen. Per cent.
Oahu	·411	..	·348	..	·269	..	·119
Kauai	·504	..	·358	..	·237	..	·246
Maui	·691	..	·401	..	·200	..	·222
Hawaii	·833	..	·353	..	·321	..	·388
Whole Group	·693	..	·366	..	·268	..	·290

Maxwell also determined the solubility in 1 per cent. of citric acid, of lime, potash and phosphoric acid in a number of typical soils. The averages of his results (calculated by the present writer) are as below :—

	Lime. Per cent.		Potash. Per cent.		Phosphoric Acid. Per cent.
Highest	·281	..	·084	..	·0125
Lowest..	·030	..	·009	..	·0012
Average	·113	..	·033	..	·0043

The low amount of available phosphoric acid in proportion to the great amount actually present is due to the accompanying ferric oxide, which is present in very great amount. Hilgard, in examining Hawaiian soils, calls attention, too, to the high content of phosphoric acid—" exceeding all others on record," and, at the same time, emphasizes the action of ferric oxide in rendering the phosphoric acid unavailable.

Other Hawaiian soils examined by him, while containing large amounts of nitrogen, were yet ' nitrogen hungry.' The percentage of nitrogen in the humus of these soils was low, and Hilgard is inclined to attribute more importance to the nitrogen in the humus than to the total nitrogen. Mr. C. F. Eckart, however, has pointed out to me that a very large proportion of the soils of the Hawaiian Islands is acid ; and hence they are not in a condition suited for nitrate formation without some previous treatment.

British Guiana Soils.—The soils of this Colony have been critically examined by Harrison[3]. He distinguishes eight types of soil, of which only three occur within the part where the cane is cultivated. These three are :—

1. The clay soils of the alluvial coast lands.
2. The sand reef soils of the alluvial coast lands.
3. The peaty or ' pegass ' soils of the alluvial coast lands.

Of these soils he writes :—

" Experience has indicated to us that in Class I. we find soils of marked fertility : soils which, with careful cultivation and tillage, should not alone retain their fertility for long periods, but give gradually increasing returns. These are the sugar cane and rice lands of the colony.

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* These averages have been given me through the courtesy of Mr. C. F. Eckart.

FIG. 11.
PURPLE
BAMBOO.

1
2

PLATE III

"In Class II. we have the soils which are not infrequently met with in belts known as sand reefs crossing sugar estates. They are to a great extent practically useless for economic cultivation.

"Class III. consists of soils frequently characteristic of parts of the sugar estates, and of which much of the swamps and wet Savannahs of the back parts of the alluvial coast lands consists. They also are found very commonly at short distances back from the banks of the lower parts of our rivers and creeks. As indicated earlier in this report, they are essentially peat soils, and as such are unsatisfactory and difficult to work. But given tillage, drainage, and amelioration of their texture by admixture with the underlying clays, they offer mines of wealth of plant food for future agriculturists in this colony."

Harrison states that—

"The alluvial soils of British Guiana are largely derived from seaborne mud from the Amazon river, and are not delta soils of the Guianan rivers."

The mean composition of the coast soils included in Class I. he gives as—

	Per cent.	
Nitrogen	·209	
Lime	·212	Soluble in 20 per cent. hydrochloric
Potash	·425	acid at the temperature of boiling
Phosphoric Acid ..	·072	water over five working days.

A tract of virgin savannah land, situated six miles west of the Berbice river and four miles from the coast, was found by the writer to be of the following average composition :—

	Total quantities per cent.* on air dry soil.		Soluble in 1 per cent. citric acid with 5 hours' continual shaking.
Lime	·153	....	·0312
Magnesia	·539	...	·2635
Potash	1·467	...	·0162
Phosphoric Acid	·093	....	·0034
Humus	6·013	....	—
Nitrogen	·479	....	—

The soil was a tenacious grey clay underlying a layer of 'pegass' from three to six inches deep, and was sampled to a depth of one foot.

Egyptian Soils.—The Egyptian soils upon which the cane is culti-vated are in Upper Egypt, and lie in a narrow strip on both banks of the Nile ; the soil is all an alluvial deposit of great depth, overlying a basis of sand, and has been formed, and is continually renewed, by the overflow of the Nile. Numerous analyses have been made of these soils, many of which have been collected by Pellet and Roche.[9] They remark :—

"The soil of this district is very uniform in its general composition ; the percentage of calcium carbonate is from 5 to 7, of sand from 20 to 60, of clay from 20 to 60, of humus ·8 to 1·3.

"The very compact nature of the greater part of the soils attracts attention, and certainly influences to a greater or less extent the availability of the fertilizing elements.

"Very remarkable is the presence, rare in arable soils, of a large quantity of magnesia, from 1 per cent. to 3 per cent.

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* Determined by decomposition with sulphuric acid and ammonium fluoride.

"The fertilizing elements, properly so called, were found per kilogram :—
Phosphoric acid .. .. ,. 1·44 to 2·30, mean, 1·75 grms.
Potash .. .. 1·56 to 3·68, ,, 2·28 ,,
Organic nitrogen.. .. .. ·37 to 1·40, ,, ·72 ,,
Nitric nitrogen, trace to .. — ·040, ,, ·004 ,,
"Finally, the quantities of chlorine and sulphuric acid which have so great an influence on the formation of efflorescent salts injurious to vegetation were found in healthy soils.
Chlorine.. .. .. ·10 to ·06 per 1000.
Sulphuric acid .. .. ·25 to 1·60 per 1000."

The average composition of 28 samples of sugar cane soils is thus given by these authors :—

True density	2·23	Potash	·228
Apparent density	1·15	Lime	2·49
Moisture	6·30	Magnesia	2·87
Chalk	6·40	Iron and Alumina	10·52
Sand	45·80	Manganese	·084
Clay	36·40	Organic nitrogen	·072
Humus	1·17*	Nitric nitrogen	·0004
Phosphoric acid	·175	Chlorine	·005
Sulphuric acid	·073		

* Schloesing's method.

The quantities given are the percentages soluble in nitric acid, according to the official French method.

The mean of seven analyses of Egyptian soils made by Mackenzie and Burns[10] with hydrochloric acid as solvent gave the following results :—

Phosphoric acid	·246	Manganese	·26
Potash	·615	Chlorine	·064
Lime	·418	Organic nitrogen	·082
Magnesia	·270	Nitric nitrogen	·0018
Iron and Alumina.. ..	22·15		

Louisiana Soils.—Stubbs[11] thus summarizes the sugar soils of Louisiana :—

Our soils, then, of the sugar belt lying along the Mississippi River and its numerous bayous, may be considered as varying from silty loams to very stiff clays.

There are also the red and brown lands, varying from sandy loams to loamy clays of the Red River and its outlying bayous, the Teche, the Boeuf, the Cocodrie and Robert, which have been formed by a similar process by the Red River, though drawn from a much more restricted area of country.

The prairie lands west of Franklin, varying in character from black stiff clays to silty loams, are our bluff lands second hand, which have been removed from the western bank of the Mississippi River and spread out over the marshes of south-western Louisiana. These bluff lands occur *in situ* on the eastern bank, running continuously from Baton Rouge to Vicksburg, giving us several parishes in which sugar cane is grown. These are usually silty loams, and are also of alluvial origin, though antedating the present Mississippi River. The bluff and prairie lands, and the alluvial deposits of the Red and Mississippi Rivers and their bayous, give the soils upon which the sugar cane of Louisiana is grown.

As the result of many samples Stubbs gives the following average. Contents of the soils in the sugar belt : Lime, ·5 per cent. ; potash, ·4 per cent. ; phosphoric acid, ·1 per cent. ; nitrogen, ·1 per cent.

Peruvian Soils.—The following account of Peruvian soils is abridged from Sedgwick.[12]

The cane area of Peru lies on the western slope of the Andes, between that range of mountains and the sea, the latitude of the largest district being 7° S. The cultivated areas lie in valleys of a very gentle slope seawards, the drainage notwithstanding being excellent. The depth of the soil is from two to twenty feet, and it varies in character from a fine sandy loam to silt.

The soils are of the alkali type, and especially towards the sea contain considerable quantities of water-soluble chlorides, sulphates and carbonates.

The soils are well supplied with plant food, the lime, much of which is present as carbonate, being very high compared with that found in the cane soils of other districts; the total phosphoric acid and potash are also good ; the nitrogen is very variable, dependent upon the time the soil has been in cultivation, the water supply, the class of weeds, and the amount of flood waters required to cover the fields.

The humus and organic matter are both higher than would be expected in the soils of an arid district.

Sedgwick gives thirty analyses of soils from the Cartavio estates, from which the present writer has calculated the averages. The analyses are presumably made by the official American method.

	Maximum.	Minimum.	Mean.
Insoluble matter	79·50	49·22	63·71
Ferric oxide	8·10	4·00	5·38
Alumina	7·50	1·59	4·78
Lime	6·75	·65	2·98
Magnesia	2·57	·23	·92
Potash	·60	·16	·33
Phosphoric acid	·43	·16	·24
Sulphuric acid	·88	·05	·18
Humus	1·84	·42	1·26
Potash sol. in 1 per cent. citric acid	·0258	·0050	·0121
Phos. acid sol. in 1 per cent. citric acid	·0630	·0081	·0337

It is interesting to compare these soils with the equally productive ones of the Hawaiian Islands. These soils are 'acidic,' and contain much more silicates insoluble in hydrochloric acid than do the 'basic' soils of Hawaii, the latter containing much more ferric oxide, and it is as a consequence of this that the availability of the phosphoric acid in the Hawaiian soils is so much less than in the Peruvian. The high content of the Peruvian soils in lime is, too, a factor which should contribute to their continued fertility.

Cuban Soils.—The soils of Cuba upon which the cane is grown are divided by F. S. Earle[13] into three classes, and are thus described by him :—

The Red Lands.—These are found mainly in Havana and Matanzas Provinces, but they occur also in eastern Pinar del Rio and in certain areas near the coast in the three eastern provinces. This red soil has many peculiar qualities. It is very sticky when wet and is heavy and difficult to cultivate, and yet it allows water to pass through it as readily as through the lightest sand. Within a few hours after a heavy shower, if the sun shines, the surface will begin to dry, and it will be possible to run ploughs and cultivators. There is no subsoil, as the red surface soil extends down practically unchanged to the bed rock, which is always a cavernous limestone pierced with numerous subterranean passages which provide a perfect natural under-drainage. There are very few streams or rivers in the red lands, as the rain water sinks so readily into the soil and is carried off by these underground passages, finally finding a vent in great springs, many of which come out in the bottom of the sea, forming the spots of fresh water which are known to occur along certain parts of the Cuban coast. This remarkable natural drainage makes these soils easy to cultivate during the rainy season, but for the same reason they become too dry for most crops during the winter, except where artificially watered. Irrigation on a large scale will always be difficult on these lands, on account of lack of available streams, and because so much water will soak away in the canals and ditches that a large head will be required in order to cover a comparatively small area.

Taking everything into consideration, these lands are probably the most satisfactory on the island for sugar production. With good management and with favourable seasons the best black lands will yield somewhat heavier crops ; and it is claimed by some that the cane from black lands is somewhat richer in sucrose ; but the crop on the red lands is always certain ; never being injured by excessive rains, and it is always possible to give sufficiently frequent tillage to keep down the weeds. The cultivation is cheaper also, as no expensive drainage ditches are needed, and no ridging up of the rows is required, level culture being best for these lands. The red soil is well supplied with the mineral elements of fertility, and, on account of its depth, it stands successive cropping for many years. No soils respond better to the use of fertilizers, and none can be built up more quickly by the growth of leguminous crops for green manuring.

Black Soils with a White Calcareous Subsoil.—These occupy large areas in the hill regions in the northern and central parts of Havana and Matanzas Provinces. Similar soils occur also in the eastern provinces, usually where the country is more or less rolling. When first cleared such lands are very fertile, but their hilly character subjects them to constant loss from washing during heavy rains. Their durability depends upon the original thickness of the top soil, and on the steepness of the hills and the consequent degree of loss from washing. These soils are fairly permeable to water, but not nearly so much so as the red soils. On account of their more retentive character they cannot be cultivated so quickly after rains, nor, on the other hand, do they suffer so quickly from drought during the dry season. Ditching is seldom necessary except sometimes on the lower portions ; the uneven surface usually affords drainage, and it can be aided by slightly ridging up the rows during cultivation. On the steeper and more broken of these lands, much of the loss from washing could be avoided by terracing or running the rows in irregular circles following the contour lines, as is done so universally in cotton fields on the broken hill lands of the Southern United States. These irregular, crooked rows seem unsightly and awkward to those who are not accustomed to them, but when properly laid out they are very effective in preventing loss from washing.

Black Lands with impervious Clay Subsoil.—The black lands that are underlaid with a stiff impervious clay present some of the most difficult problems to the sugar planter. They are naturally very fertile, and, when conditions are favourable, they yield maximum crops. But most of these lands are quite level, and the subsoil

holds the rainfall, so that the cane often suffers from a lack of drainage. In wet seasons, too, it is difficult, or often impossible, to give sufficiently frequent cultivations to keep down the weeds. These troubles are not so obvious when the land is new, as the immense number of decaying roots leave the soil more or less open and porous, so that the surface water passes away more readily. With age the soil settles together and becomes more compact and impermeable. All old lands of this class will be greatly improved by establishing a carefully planned system of drainage ditches and keeping them always well cleaned. Ridging up in cultivation, so as to leave deep water furrows between the rows, will also be very advantageous.

Queensland Soils.—The sugar cane soils of Queensland have been subjected to survey by Maxwell[14]. He divides the soils of Queensland into three districts, the Southern or Bundaberg, the Central or Mackay, and the Northern or Cairns.

Dr. Maxwell subdivides the soils of the southern district into four classes; the red soils, derived from true basaltic lavas; the mixed dark and light red and yellow red soils, derived partly from basaltic lavas and partly from eruptive action upon other rock formations; soils more rather than less of sedimentary origin, and soils derived exclusively from older rock formations.

The Mackay soils are of an acidic type formed from the decay of mixed siliceous rocks, and are in sharp distinction to those of the Bundaberg district.

The average analysis of the soils from the Mackay and Cairns district is thus found by Maxwell :—

	Lime. Per cent. Total.	Potash. Per cent. Total.	Phosphoric Acid. Per cent. Total.	Nitrogen. Per cent. Total.	Lime. Per cent. Available.*	Potash. Per cent. Available.*	Phosphoric Acid. Per cent. Available.*
Cairns	·292	·310	·141	·122	·0654	·0132	·0010
Mackay	·829	·223	·165	·122	·1119	·0222	·0020

Java Soils.—De Meijier[15] states that the soils of Java are formed from the decomposition of the volcanic rock (andesite) forming the mountain ranges of Java: the resulting soils are clays, those of West Java being generally very heavy and compact and requiring considerable moistening before ploughing. In East Java there is evidence of the products of vulcanism—the soils are lighter and sometimes more fertile. The native term *Tanah ladoe* is applied to a mixed clay and sand soil, and *Tanah lindjad* to a heavy clay.

The soils of Java have, of course, been subjected to rigid examination ; the analyses published by Kramers[16] are the most complete. The mean of thirty analyses of East Java soils by him gives :—lime 1·9 per cent. ; magnesia ·2 per cent.; potash ·07 per cent.; phosphoric acid ·06 per cent.; nitrogen ·07 per cent. A number of soils from West Java[16] give as an average lime ·7 per cent.; magnesia ·06 per cent.; potash ·06 per cent.; phosphoric acid ·06 per cent.

Mechanical analyses of the soil show from 10 per cent. to 30 per cent. of fine sand less than ·5 mm., and from 50 per cent. to 90 per cent. of clay.

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* Aspartic Acid Method.

REFERENCES IN CHAPTER V.

1. *Le Canne à Sucre*, p. 38.
2. *Cultur de la Canne à Sucre*, p. 33.
3. *Ensayo sobre el cultivo de la canne de azucar.*
4. *I. S. J.*, 84.
5. *Bull. Assoc.*, 1899, p. 1186.
6. *Bull.* 1A *Agric. H.S.P.A.*
7. *Soils*, pp. 297, 356.
8. *Report, Brit. Guiana Gov. Lab.*, 1903.
9. *Bull. Assoc.*, xxiv., p. 1691.
10. *Khed. Agric. Soc. Jour.*
11. *Sugar Cane*, p. 49.
12. *On the Sugar Industry of Peru.* Trujillo, 1905.
13. *Bull.* 2, *Est. Cent. Agron. Cuba.*
14. *Reports, Bur. Sug. Exp. Sta.*, 1902-05.
15. *Proc. Am. Soc. Civ. Eng.*, 54, 34.
16. Quoted in Krüger's *Das Zuckerrohr.*

CHAPTER VI.

THE MANURING OF THE CANE.[*]

The cane, in common with other economic plants, has received extensive manurial trials; from the many published statements available certain of the results are abstracted below, arranged under the districts in which they were made.

British Guiana.—Scard[1], as the result of an extended series of experiments on the Colonial Company's Estates in British Guiana, concluded:—

1. That lime used by itself gave a small pecuniary gain.

2. That lime associated with manures gives an increase sufficient to pay for itself only when used with larger (2 cwt.) quantities of soluble nitrogen, such as sulphate of ammonia.

3. That of nitrogenous manures, sulphate of ammonia at the rate of 2 cwt. per acre gives the best results.

4. That ground mineral phosphate appears to give an increased yield compared with superphosphate.

5. That guanos, especially in conjunction with lime, fall far short of ammonia in beneficial effect.

6. That an increase of phosphoric acid over the minimum employed (168 lbs. per acre) fails to give satisfactory pecuniary results.

7. That neither lime nor manures produce any perceptible difference in the purity of the juice but only affect the weight of cane.

Harrison[2] concluded as a resumé of work on cane manuring:—

1. That the weight of cane is governed by the amount of readily available nitrogen either naturally present or added as manure.

2. When applied in quantities containing not more than 40 to 50 lbs nitrogen per acre, sulphate of ammonia and nitrate of soda are equally effective manures on the majority of soils, but that when the unit of nitrogen is of equal money value it is more economical to supply the former. Dried blood and similar organic manures in which the nitrogen only slowly becomes available are distinctly inferior sources.

3. Under ordinary conditions of soil and climate and the usual range of prices for sugar, it is not advisable to supply more than 2 cwt. of sulphate of ammonia or 2¾ cwt. of nitrate of soda per acre.

4. If circumstances arise in which it is desirable to obtain the maximum yield per acre by the application of more than 50 lbs. nitrogen per acre, sulphate of ammonia should always be used.

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[*] I write *Manuring* in preference to *Fertilization*, the term used in the United States, for by the latter is properly understood the process of impregnating the female organs of the cane flower.

5. Practically on all soils manurings with nitrogen require to be supplemented by phosphoric acid. The most effective form appears to be superphosphate of lime and slag phosphate meal. Mineral phosphates are of distinctly lower value and are not effective unless applied in quantities far exceeding in value those required for either superphosphate or slag phosphate meal; as a rule phosphates should only be applied to plant cane, their action on ratoons being limited.

6. On some soils the application of potash salts in quantities from 60 to 160 lbs. sulphate of potash per acre results in greatly increasing the effectiveness of nitrogenous manuring. Soils containing less than ·01 per cent. potash soluble in 1 per cent. citric acid will as a rule respond favourably to this treatment, while those containing between ·01 per cent. and ·02 per cent. may or may not be favourably affected.

Harrison[3] has also given a resumé of the results obtained from twenty-four years' experimental work in British Guiana. A short abstract of these results is given below :

Lime.—Alternate beds of heavy clay land were treated with five tons of slaked Barbados lime per acre. The canes were grown up to third ratoons and then fallowed for a year. In the plots which were manured in addition to liming, the total increase due to liming was 37·0 tons of cane per acre, and in the unmanured plots at the rate of 33·7 tons per acre. Both the above increases refer to the sum total of ten crops harvested in 13 years.

Phosphates.—Applications of phosphates have not always resulted in financial benefit. It appears that the most satisfactory mode of using phosphates is to apply 3 cwt. of superphosphate or 5—6 cwt. of slag phosphate to plant canes, the dressings of slag phosphate being more remunerative than those of superphosphate of equal cost. Phosphates do not benefit ratoons and Prof. Harrison thinks it doubtful if it is necessary to apply phosphates to Demerara soils as often as once in five years.

Potash.—Results obtained with both sulphate and nitrate of potash indicate that potash is not required on the heavy clay soils of British Guiana under the conditions of ordinary agricultural practice.

Nitrogen.—As the mean result of ten crops of cane in 13 years it was found that 10 lbs. of nitrogen as sulphate of ammonia, when added in proportions up to 300 lbs. per acre, gave an extra return of 1·3 tons of cane per acre, or 2⅓ cwt. commercial sugar. With nitrate of soda up to 250 lbs. per acre, 10 lbs. of nitrogen would probably give 1·4 tons of cane, equal to 2½ cwt. of commercial sugar, but experiments indicate that it is not wise to apply more than 250 lbs. nitrate of soda at one dressing. With dried blood the indications over eight crops were that the relative value of nitrogen in this material was 73 per cent. of that in sulphate of ammonia.

With regard to the effect of manures on the soil, Prof. Harrison comes to the following conclusions, basing his results on the analytical figures obtained by the extraction of the soil in 1 per cent. aqueous citric acid with five hours' continuous shaking :—

1. That the growth of the sugar cane without nitrogenous manuring is accompanied by a considerable loss of the nitrogen in the soil, amounting in ten years to 18·6 per cent. on not limed land, and to 26·7 per cent. on limed land. These are equivalent to losses from the soil to a depth of eight inches of 880 lbs. and 1250 lbs., respectively, per acre.

2. Repeated heavy dressings with farmyard manure have resulted in an increase in the total nitrogen of the soil. In ten years the increase was 20·3 per cent., equal to 960 lbs. of nitrogen per acre added to the soil to a depth of eight inches.

3. The growth of the sugar cane on plots receiving only nitrogenous manures has resulted in losses of soil nitrogen : where sulphate of ammonia was applied, the loss amounted to 14·7 per cent., or to 670 lbs. of nitrogen, and where nitrate of soda was used, to 16·3 per cent., or to 775 lbs. of nitrogen per acre, in the soil to a depth of eight inches.

4. On soils manured with phosphates, potash, and nitrogen in the form of sulphate of ammonia, the loss of soil nitrogen in the top eight inches amounted to 14·7 per cent., or to 700 lbs. per acre, while where nitrate of soda was the source of nitrogen the loss was far higher, amounting to 26·5 per cent., or to 1250 lbs. per acre.

5. The soil in 1891, at the commencement of the experiments, yielded ·0142 per cent. of phosphoric anhydride to a 1 per cent. aqueous solution of citric acid. After ten years' cropping without manure it yielded ·0086, which shows a loss of nearly 40 per cent. of the probably available phosphoric anhydride, or of, in round figures, 170 lbs. per acre.

6. Where the soil received manures not containing phosphates, the proportion of probably available phosphoric anhydride was reduced to ·0096 per cent., equal to a loss of 32·4 per cent., or to one of, in round figures, 140 lbs. per acre.

7. Where superphosphates were used in addition to nitrogenous manures, the proportion of probably available phosphoric anhydride was reduced to 0·132 per cent., indicating a loss of 7 per cent., or of 30 lbs. per acre.

8. Where slag-phosphates had been applied, the probably available phosphoric anhydride has been reduced to ·0102 per cent., equal to a loss of 28·1 per cent., or to one of 120 lbs. per acre. It is worthy of note that in our more recent experiments, while manuring with slag-phosphates produced on the plots which had received superphosphates during the earlier years of the experiments mean increases of only 2–3 per cent., they produced on those which had been manured with slag-phosphates a mean increase of 5–8 per cent.

9. The determinations of potash soluble in 1 per cent. citric acid and in 200th normal hydrochloric acid showed that cultural operations have made probably available more potash each year than is required for the growth of the sugar cane, the original samples yielding potash at the rate of 262 lbs. and 278 lbs. per acre to a depth of eight inches, those not manured with potash salts during ten years at the rates of 376 lbs. and 500 lbs., and those which received potash salts in addition to nitrogenous manures at the rates of 357 lbs. and 530 lbs.

10. Judging from the solubility of the lime in the soil in 200th normal hydrochloric acid, cultural operations set free in a soluble form more lime than the crops utilized, the original soil yielding lime to the solvent at the rate of, in round figures, 3400 lbs. per acre to a depth of eight inches, while the samples taken after ten years' cultivation yielded at the rate of 3800 lbs. The soils which received in July, 1891, slacked lime, supplying in round figures 6700 lbs. lime per acre, yielded to the acid in 1902 a mean of 5000 lbs. per acre, thus indicating after ten years' cultural operations a retention in the uppermost layer of the soil of only 1200 lbs. of added lime in a readily soluble form.

11. The action of the lime on the solubility of the potash in the uppermost layer of the soil appeared well marked, the samples from the not-limed land yielding to 200th normal hydrochloric acid at a mean rate of 460 lbs. potash per acre to a depth of eight inches, while those from the limed land yielded at the mean rate of 640 lbs.

Finally, as a result of these analyses and experiments, Prof. Harrison lays down certain precise and formal propositions of the greatest value to the agricultural chemist responsible for the economic manuring of large areas of sugar cane. These may be summarized as under :—

1. Soils which yield ·007 per cent. phosphoric anhydride to 1 per cent. aqueous citric acid with five hours' continuous shaking will not as a rule respond to manurings with phosphates.

2. Under similar conditions soils yielding ·005 per cent. to ·007 per cent. will benefit as a rule by phosphatic manurings.

3. It is advisable to apply heavy dressings of slag-phosphates or lighter ones of super or basic phosphates to soils yielding less than ·005 phosphoric anhydride.

4. Soils yielding ·008 per cent. potash can be regarded as containing under the usual system of cultivation sufficient available potash for the needs of the sugar cane.

5. If the potash lies between ·005 per cent. and ·008 per cent. it is doubtful if the application of potash salts will result in remunerative returns.

6. Where the potash falls below ·005 per cent. it is advisable to add potash salts in the manures.

7. The demand of the sugar cane for lime as a plant food is low, and if a soil gives up more than ·006 per cent. to the 1 per cent. citric acid solution, it probably will yield sufficient for plant food for ordinary crops of sugar cane.

Barbados.—Harrison and Bovell[4] in a series of experiments, carried out between 1885 and 1889 at Dodd's Reformatory in Barbados, came to the general conclusions detailed below : —

1. The addition of readily available nitrogen to mineral manures produces a large increase in the weights of cane grown, but excessive dressing (over 3 cwts. sulphate of ammonia per acre) may cause a marked decrease in the richness and purity of the juice.

2. Under certain climatic conditions, manuring with nitrogen in form of slowly decomposing organic matter may, if applied before or soon after the planting of the canes, produce excellent results. Applications of such slow acting manures in June or July at the period of the sugar cane's most active growth are unadvisable, and may result in considerable loss.

3. Upon the soil, and under the climatic conditions existing at Dodds' during the years 1885 to 1889, both inclusive, nitrate of soda was markedly inferior to sulphate of ammonia as a source of nitrogen for sugar cane.

4. The profitable employment of purely nitrogenous manures depends largely upon the state of the soil. If the soil is in good heart, such applications may realize heavy returns, if poor such manurings will result in heavy loss.

5. For the maximum return of sugar cane by manuring, phosphates must be present in the manures used.

6. If such phosphates are applied in the form of superphosphate of lime, great care must be exercised in their use and application, as whilst light dressings of superphosphate capable of supplying 75lbs. or 80lbs. per acre of "soluble phosphate" (equivalent to from 16 to 18 per cent. of "soluble phosphates" in commerical sugar cane manures when applied at the rate of one ton to five acres), may produce large increases in the weights of canes, &c., heavier dressings do not produce corresponding increases, and excessive ones may even reduce the produce below that obtained when manuring with nitrogen and potash only.

7. The use of insoluble phosphates such as precipitated and mineral phosphates is not advisable during the period of the cane's active growth, but may produce excellent results when applied to the soil at an early period, in a very fine state of sub-division in large quantities, and uniformly mixed with it. To obtain, however, equally profitable results with these phosphates, as with moderate applications of superphosphates, it is absolutely necessary that they be purchasable at far lower prices than they can be at present obtained in Barbados.

8. The addition of potash to manurings of phosphates and nitrogen produces in all soils at all deficient in available potash large increases in the yield of cane and of available sugar in the juice per acre.

9. The most advantageous time for the application of potash-containing manures appears to be at the earliest stages of the plants' growth, and pecuniarily the use at this period of so-called early cane or potassic manures is far preferable to that of even the highest quality of manures which were formerly used.

10. The presence of an excess of potash in the manures does not injuriously affect the purity of the juice, either by increasing the glucose or appreciably the amount of potash salts contained in it.

11. No definite information has been obtained with regard to the influence of the mineral constituents of the sugar cane manures upon the saccharine richness of the canes; although, in the great majority of cases, canes receiving potassic manures have been somewhat richer in sugar than those otherwise manured. It appears, therefore, probable that increased saccharine richness must be sought in the cultivation of varieties, the careful selection of tops for planting from healthy and vigorous canes (by this selection, whilst the saccharine strength of best canes of a variety would not be increased, the average might be greatly raised), and possibly by the seminal reproduction of carefully selected canes and varieties.

Mauritius.[5]—A series of experiments made by Bonâme at the Station Agronomique in Mauritius gave the results detailed below :—

			Return in Tons of Cane per acre.					
Manure.	Plant Cane.		First Ratoons.		Second Ratoons.		Mean per Year.	
a, m, q, u..	51·400	..	35·710	..	26·690	..	39·600	
b, m, q, u	61·100	..	31·460	..	27·040	..	41·500	
c, m, q, u..	60·890	..	37·800	..	26·480	..	41·729	
d, e, f, m, q, u	61·300	..	36·000	..	25·770	.	41·020	
g, h, i, n, r, u.. ..	54·210	..	34·790	..	25·820	..	39·030	
j, k, l, o, s, w	48·360	.	30·530	..	23·030	..	33·940	
Nothing	42·680	.	20·090	..	14·330	..	25·630	
d, e, f, m, q	31·720	..	18·000	.	10·910	..	20·210	
d, e, f, u	29·510	..	15·430	..	11·130	..	18·690	
m, q, u..	35·660	..	21·820	..	13·610	..	23·530	
d, e, f, p, u	64·610	..	37·040	..	29·900	..	43·850	
d, e, f, t, u	64·680	..	39·760	..	31·790	..	45·410	
d, e, f, r, u	62·610	..	39·980	..	30·920	..	44·500	
d, e, f, m, q, u	58·100	..	39·350	..	30·410	..	42·950	
d, e, f, m, q, v.. ..	57·400	..	38·080	..	31·530	..	42·330	
d, e, f, p, q, v	52·700	..	36·560	.	29·080	..	37·440	
d, e, x, m, q, u ..	46·100	..	34·620	..	24·360	..	35·020	
m, q, u..	39·450	..	28·370	..	20·729	..	29·510	
d, e, f, u	27·670	..	20·400	..	13·290	..	20·450	
d, e, f, m, q	21·200	..	14·310	..	6·880	..	14·130	

a, 30 kilos nitrogen as dried blood, b as sulphate of ammonia, c as nitrate of soda. d, 10 ,, ,, ,, ,, e ,, ,, f ,, ,, g, 13·3 ,, ,, ,, ,, h ,, ,, i ,, ,, j, 6·6 ,, ,, ,, ,, k ,, ,, l ,, ,, m 20, n 6, o 13·3, p 40 kilos soluble phosphates ; q 20, r 26·6, s 13·3 kilos in soluble phosphate ; t 40 kilos citrate soluble phosphates ; u 30, v 40, w 20 kilos potash ; x 20 kilos nitrogen as nitrate of soda.

Hawaii.—The result of a series of experiments led C. F. Eckart[6] to the following conclusions :—

1. Lands, capable of producing eleven tons of sugar to the acre without fertilization, may be fertilized with profit, climatic conditions and water supply being favourable.

2. While soils of high fertility may respond to mixed fertilizers, the percentage of gain is greater as the soils suffer a gradual exhaustion.

3. The Rose Bamboo and Lahaina varieties of cane did not show the same response to various combinations of fertilizer ingredients.

4. It is indicated that Rose Bamboo requires a larger store of phosphoric acid to draw from than Lahaina for the best results.

5. Lahaina cane responded more to an increased supply of potash in the soil than Rose Bamboo.

6. Both Rose Bamboo and Lahaina cane showed a considerable gain in yields from fertilization with nitrogen. The percentage of this element in the soil on which the tests were carried out was below the average for the islands.

7. On a soil containing phosphoric acid (soluble in a 1 per cent. solution of aspartic acid) in quantities which were in large excess of those contained in the average soil, phosphoric acid applied with nitrogen gave yields of Rose Bamboo cane exceeding those obtained when nitrogen was applied alone. Under the same conditions, Lahaina cane gave about the same yields following fertilization with nitrogen as when nitrogen was applied with phosphoric acid.

8. On a soil containing potash (soluble in a 1 per cent. solution of aspartic acid) in quantities comparing closely with those of the average island soil, Rose Bamboo and Lahaina cane gave increased yields when this element was applied with nitrogen.

9. The separate application of phosphoric acid in soluble forms to lands standing high in phosphoric acid may result in a loss of sugar rather than in a gain. It is indicated that the chances of loss are greater with Lahaina cane than with the Rose Bamboo variety in localities where the two varieties make an equally thrifty growth under normal conditions.

10. Separate applications of potash in the form of sulphate of potash may decrease the yields of cane. The danger of loss is apparently greater with Lahaina cane than with Rose Bamboo. This refers to applications of potassium sulphate to lands under cane.

11. The fact that the application of one particular element gives negative results with respect to fertilization does not warrant the assumption that the element in question may, with profit, be omitted as a component part of mixed fertilizers. Applied with another element, the gains may be considerably greater than could be obtained with the latter element alone.

12. With both varieties the purest and richest juice was obtained from the cane on the unfertilized area. In general, the plats receiving incomplete fertilizers yielded juices of greater purity than those plats to which the three elements were applied together.

Later experiments have resulted in the same authority stating[7] :—

1. The profit resulting from the application of fertilizers or manures will depend largely upon other factors than the chemical composition of the soil. Providing certain plant food deficiencies represent the chief depressive influence on crop yields, the response to appropriate fertilization will be commensurate with the difference between the limitations exerted upon crop production through lack of available plant nutrients and the limitations exercised by the next restraining factor in order of importance after the material has, been applied. This latter factor may be physical, biological or climatic in character.

2. The relative effects of different combinations of fertilizer materials on the growth of sugar cane when these materials are added to a given soil will be determined chiefly by

(a) the extent to which their several ingredients directly or indirectly lessen the deficencies of available plant nutrients ;

(b) the extent to which they cause the bacterial flora to approach an optimum balance for the regular production of sufficient nitrates or assimilable nitrogen compounds, and

(c) the degree and manner in which they produce physical changes in the soil.

3. Owing to the fact that a definite relationship exists between the efficiency of a fertilizer mixture and the quantities and proportions in which its ingredients are associated, due to biological, chemical and physical effects which its component parts have in a given soil, variations in the composition of the mixture beyond certain limits may materially influence crop yields.

4. A more definite knowledge concerning the amounts and proportions of fertilizer salts to use in a mixture for best results would on some soils yield pronounced profits, while a lack of such knowledge may in some cases result in a loss, especially when soluble salts are employed.

5. The greatest loss from the use of improper mixtures of fertilizers is apt to occur on acid soils, and in such cases considerable risk is involved from the continued application of mixtures containing ammonium sulphate, sulphate of potash, and acid phosphate, when lime dressings are not previously made.

6. While the chemical and physical analysis of a soil will usually prove of value in indicating the best cultural methods to follow in maintaining or improving its fertility, and may also indicate in a general way certain of the plant food deficiencies in given cases, it cannot afford definite information as to the amounts or proportions of ingredients in fertilizer mixtures which will give maximum returns.

7. It is possible that the data from more extended field experiments with a large variety of soils, when reviewed in connection with the comparative analysis of the soils, using both weak and strong acids as solvents, may indicate a somewhat definite relationship between the analytical figures and the order of importance which phosphoric acid and potash should assume in cane fertilizers in given cases.

8. It would appear that analysis of soils, with more special reference to their physical qualities, reaction and content of organic matter, nitrogen, and more readily soluble lime, may, with due consideration of the water supply and climatic conditions, be relied upon to indicate such manurial treatment as will result in a profit, although they will not afford definite information as to the weights and proportions of ingredients in fertilizer mixtures which will result in maximum efficiency.

9. Nitrogen is the most important element to be considered in the fertilization of the sugar cane in the Hawaiian Islands, and when applied in mixed fertilizers some risk of reduced efficiency is entailed if either the potash or phosphoric acid (in the form of soluble salts) is made to exceed the weight of this element.

10. Unless through past local experience or carefully conducted field tests, it has been definitely determined that a modified formula may be expected to give greater yields, it is safer, when applying nitrogen, potash and phosphoric acid in the form of soluble salts, to have the mixed fertilizer contain even quantities of these elements, which are not to exceed 60 lbs. per acre in the case of each element.

11. Field tests with fertilizers whose ingredients are mixed in varying proportions will, if such experiments are accurately and scientifically conducted through a sufficient period, give the most reliable information as to the best manurial practice. Such experiments should be laid out in very long, narrow, parallel and contiguous plats or strips, with the untreated check areas lying immediately adjacent to the fertilized cane.

12. The great importance of 'resting' fields in rotation on Hawaiian plantations, and growing upon them leguminous crops is very clearly indicated. This applies more particularly to the irrigated plantations, where the supplies of organic matter are in the majority of cases becoming greatly reduced through successive tillage operations in a comparatively arid climate, and by the favourable conditions created for bacterial activity through regular irrigations under uniformly high temperatures.

Java.—Repeated experiments in Java[8] have shown that under conditions there prevailing, manuring with readily available nitrogen alone leads to the best financial results. The flooding of the fields during the period that they are under rice brings down in suspension finely divided soil, which affords a supply of potash and phosphates. In addition, the system of land tenure there prevailing does not justify the cane planter in adopting measures towards the permanent amelioration of the soil.

Effect of Manuring on the Composition of the Cane.—

There is a wide-spread belief that heavy manuring adversely affects the quality of the juice of the cane and under certain conditions this may be correct; thus in a district such as Demerara, where a short period of growth obtains, a late manuring results in an impure juice. Possibly in such a case not only is the maturity of the crop delayed but a second growth of young cane is stimulated and the comparison may become one of mature and of immature cane. Again with heavy manuring, there is a consequent increase in the size of the crop with less access of direct sunshine, and a delayed ripening is the result.

That judicious heavy manuring has no harmful effect is shown from the results regularly obtained in Hawaii; nowhere is a sweeter and purer juice obtained, and nowhere is the manuring more intense. Here, however, owing to climatic conditions peculiarly favourable, a great part of the harvest consists of fully matured cane cut at the period of maximum sweetness.

Actual experiments on this point lead to somewhat contradictory results. Thus Eckart[9] found in Hawaii with unmanured cane a sucrose content in the juice of 18·26 and purity of 90·69, manured canes affording a juice containing from 16·40 per cent. to 17·85 per cent. sucrose, and of purity 89·16 to 90·60. Conversely, however, the same authority has supplied me with data of an experiment where, in three instances, an application of 1200 lbs. of high grade mixed fertilizer and 300 lbs. of nitrate per acre not only enormously increased the yield but gave a sweeter and purer juice.

Of the specific effect of manures, many ideas, supported or not by experiment, may be met with. Lime is credited with producing a sweet and pure juice in the West Indian adage, "The more lime in the field the less in the factory," and this idea is reflected in the quotations at the beginning of *Chapter V.*

Phosphates are also believed to affect beneficially the sugar content of the cane, and potash is reputed to have the reverse effect; Harrison's experiments already quoted fail however to countenance this idea.

There is a certain amount of evidence that canes heavily manured with readily available nitrogen are more susceptible to fungus attacks than are others; this may be due to the production of a soft rinded cane due to rapid

FIG. 12.
STRIPED
BAMBOO.

$\frac{2}{3}$ SIZE

PLATE IV

growth, and possibly in the presence of infected soil or material the nitrogenous manure may also benefit the development of the fungus. In Egypt, it may be mentioned, on lands controlled by the Daria Sanieh manuring of cane was not allowed.

On the whole the writer thinks that the bulk of the evidence points to weight of cane only as being affected; differences which may from time to time be observed are probably due to different degrees of maturity or to other uncontrollable factors vitiating the comparison.

Time of Application of Manure.—The experimental study of the manuring of cane has in general pointed to the benefit accruing from early application of readily available nitrogen, and as a matter of practical experience it has been found that canes so treated make a vigorous, rapid growth and better withstand a subsequent drought. In general plant physiological experience it is found that a supply of readily available nitrogen leads to a large leaf development, and the development of the stalk of the cane is intimately connected with that of the leaf.

It is often asked if one or two applications of the same amount of nitrogen are the more beneficial. Watts' experiments in the Leeward Islands[10] point to the one application system being the better, and he reasons on the following lines :—

> " These results lead us to make the suggestion that manures applied to sugar canes will probably be found to be more efficient, both physiologically and pecuniarily, if given in quick acting forms at a very early stage of the cane's growth, and we are led to speculate if this may not be accounted for, on botanical grounds, by the structure and manner of growth of the cane. We have perhaps been too prone, when thinking of manuring crops, to have in our mind dicotyledenous-branching trees, with many growing points, instead of the sugar cane, with its one growing point, or ' top ' to each stem. The cane having lost its habit of seeding may be regarded as a growing top and a stem. When the former has arrived at its full development it may be taken roughly to be a fixed quantity; old leaves fall away and are replaced by new ones, so that the top remains fairly constant. The stem constantly receives additions, and gradually ripens to form a dormant sugar house chiefly filled with sugar, doubtless originally destined to provide for the growth of flowers and the production of the seed, but now developed to a greater extent than the feebly fertile flowers demand.

> "The elements of plant food, including nitrogen, potash and phosphate, are found in greater abundance in the ' top ' and leaves than in the stem; hence it is reasonable to suppose that in the early development of the cane plant, with its system of top and stem, greater demand is made upon the plant food supply of the soil in order to build up this top rich in plant food, than occurs later on when the top, a comparatively fixed quantity, has been developed, and additions are being made to the stem, which additions demand relatively large amounts of carbohydrates, with comparatively small amounts of nitrogen, potash and phosphates. Transference of plant material from point to point takes place freely, and it is reasonable to suppose that the cells of the stem, as they pass into the dormant condition, may pass on some of their nitrogen, potash and phosphate to be used in building up newer structures. We are aware of this transference of plant food in the case of the leaves, where the faded and falling cane leaves contain much less plant food than the actively growing ones.

"In order to have fresh information on this point analyses have been made of fresh cane leaves, and of dry cane leaves, just as they were about to fall from the plant but not actually fallen.

"The results are as follows, and show in a striking manner the nature of the transference of plant food material from the leaf back to the stem as it ripens and as its lower portion becomes dormant :—

Analysis of Ash.

	Green Leaves.		Trash Leaves.
Silica	46·26	..	63·31
Carbon	3·52	..	3·47
Iron oxide	·49	..	·38
Alumina	—	..	·03
Lime	4·68	..	6·67
Magnesia	5·08	..	5·10
Potash	17·23	..	6·49
Soda	6·60	..	3·58
Phosphoric anhydride	1·39	..	·93
Sulphuric anhydride	5·45	..	5·18
Carbon dioxide	2·39	..	1·97
Chlorine	9·09	..	1·83
Water	1·25	..	2·59
	103·43	..	101·53
Deduct oxygen equal to Chlorine	2·02	..	·40
	101·41	..	101·13
Nitrogen	·777 on dried leaves.		·36 on dried trash.

Grams of Mineral Matter in One Leaf.

One fresh cane leaf contains ·9688 grams of ash.
One fresh trash leaf contains ·5304 grams of ash.

	Green Leaf. Grams.		Trash Leaf. Grams.
Silica	·4419	..	·3321
Carbon	·0336	..	·0182
Iron oxide	·0047	..	·0020
Alumina	—	..	·0002
Lime	·0448	..	·0350
Potash	·1645	..	·0340
Soda	·0630	..	·0188
Phosphoric anhydride	·0134	..	·0048
Sulphuric anhydride	·0520	..	·0272
Carbon dioxide	·0228	..	·0103
Chlorine	·0868	..	·0096
Water	·0118	..	·0136
Deduct oxygen equal to chlorine	·0193	..	·0021
	·9586	..	·5304
Nitrogen	·094	..	·033

"If this manner of regarding the cane as a growing organism is correct, it may lead us to modify some of our ideas concerning the manuring of sugar canes, and may account for the better result obtained by applying considerable quantities of nitrogen in one dose at an early stage, and for the smaller results obtained from the use of such a slow acting manure as dried blood."

The experiments made by Watts, described above, had already been conceived as long ago as 1877 by Rouf in Martinique; his experiments and conclusions, than which I have come across none others so complete, are quoted in full from Delteil's *Canne à Sucre*. Rouf harvested, weighed and analysed month by month a crop of cane planted in March of 1877. His results, which I have translated into lbs. per acre, are given in the annexed table; they give the weight of the crop and of the various bodies contained therein: on these results he thus expresses himself:—

1. The absorption of minerals commences as soon as the development of the plant allows, but evidently it is much more active if the plant finds the necessary fertilizing principles at its disposal, and above all if the climatic conditions are favourable.

2. The progress is moderated from the sixth to the ninth month; then the march of the elements rises to the tenth and eleventh month, the time of the maximum absorption. At this period the total weight of stalks and leaves is a maximum; the cane has absorbed all the minerals and nitrogen, and the weight of dry matter also is the maximum. By the tenth month the cane has absorbed a maximum of the following elements: phosphoric and sulphuric acids, potash, soda and silica. At the eleventh month the elements which lagged behind are absorbed up to the maximum; these are lime, magnesia and nitrogen, and the elements which first reached a maximum have begun to be eliminated. In the twelfth month, the elimination of the last three elements begins and continues for all until the cane is ripe.

3. The cane should be manured early so as to place at its disposal necessary food, and to accelerate the elaboration of sugar.

4. The elimination of the excess of potash, chlorides and soda from the stalk and their transport to the top and leaves are ended when the cane is ripe. In the top of the cane are accumulated alkaline chlorides, glucose, albumenoid and pectic bodies.

The return of plant food to the soil by the plant as it ripens indicates the agricultural economy of harvesting the crop at its period of maximum ripeness as less plant food is then removed; Rouf's analyses bring out this point very clearly.

Method of Application of Manures.—On general principles the proper form of application of the various artificial manures varies.

Nitrate of soda and also nitrate of lime, being readily soluble and not being fixed by the soil (*i.e.*, rendered insoluble), are applied as top dressings.

Ammonia salts are also readily diffusible, and are applied as top dressings.

Organic forms of nitrogen requiring the action of soil organisms must be buried in the top two or three inches of the soil.

MONTHLY COMPOSITION OF THE CANE (WHOLE PLANT).
After ROUF.

Lbs. per Acre.

Age of Cane.	Green Weight.	Dry Weight.	Ash.	Nitrogen.	Phosphoric Acid.
Six months	21,054	4,072	275	20·2	10·3
Seven months	44,608	7,366	360	35·5	15·2
Eight months	73,302	10,597	444	38·0	27·3
Nine months	76,082	12,100	504	44·9	27·7
Ten months	82,008	16,290	628	55·2	39·2
Eleven months..	76,558	18,363	576	60·4	37·3
Twelve months	65,377	16,505	467	55·2	36·7
Thirteen months	79,150	17,756	468	39·8	29·0

Age of Cane.	Sulphuric Acid.	Potash.	Soda	Lime.	Magnesia.	Silica.
Six months	14·1	36·0	2·2	7·1	13·1	139·1
Seven months	14·8	44·4	8·6	23·8	15·5	168·1
Eight months	18·7	79·0	7·9	26·1	24·6	200·5
Nine months	20·0	79·7	9·7	28·4	25·7	245·3
Ten months	21·9	97·3	21·4	46·7	26·2	322·0
Eleven months..	19·4	71·5	13·6	58·4	36·7	293·3
Twelve months	14·3	62·0	8·8	33·0	25·9	232·4
Thirteen months	17·3	62·6	7·0	38·0	27·5	210·5

Cyanamide, to be assimilated by plants, must first be acted on by soil organisms, and hence is generally applied before planting, especially as this material has some harmful effect on the germination of seeds.

Superphosphates are also often applied as a top dressing, or are worked in at a very slight depth. Stubbs recommends that they should be spread over the whole area to be manured. Slag and mineral phosphates require to be thoroughly incorporated in the soil.

Potash also, being readily and completely fixed by the silicates of the soil, requires thorough incorporation.

There is no reason (and indeed in many ways it is advantageous) why phosphate and potassic manures should not be applied to the soil during the preliminary cultural operations before planting. The retention of these materials by the soil is so absolute that no loss by leaching is to be apprehended.

Valuation of Manures.—The question of the valuation of manures is a special subject of its own, and outside the scope of a work of this nature.

In more than one cane growing district all manures intended for use on plantations are analysed and controlled at the Experiment Stations now generally considered a necessary adjunct to large cane growing districts; this work but seldom falls to the estate chemist.

Taking the value of nitrogen in sulphate of ammonia as 100, the following are the average values adopted for other constituents; it should be mentioned, however, that no uniformity obtains as between different districts.

Nitrogen in ammonia sulphate	100
Nitrogen in nitrate	90
Organic nitrogen	100
Water soluble phosphoric acid	25
Citrate soluble phosphoric acid	25
Insoluble phosphoric acid..	10
Potash in sulphate..	30
Potash in chloride	25

The valuation of materials such as seed cakes, tankage and packing house refuse depends very largely on the degree of fineness of the material. This also applies to basis slags, which are usually sold under a guarantee of fineness. A slag 80 per cent. fine means that 80 per cent. of the material will pass through a sieve with a mesh of 250 wires to the lineal inch.

Lime in Connection with Cane Growing.—A study of the analyses of the ash of the cane cannot lead to the conclusion that the cane is a calciophile plant, and Harrison[3] in his resumé of twenty-five years' experimental study of the manurial requirements of the cane has come to the same conclusion.

The benefits that follow the application of lime in many districts where the cane forms the staple crop must not then be considered as due to specific action of this material on the cane, but as due to its general effect in amelioration of the soil.

The action of lime may be briefly summarized :—

1. Correction of acidity in the soil, whether due to an excess of organic matter, or due to long continued application of ammonia salts.

2. Amelioration of the physical condition of heavy clays.

3. Rendering potash available.

It is now generally considered better practice to apply moderate applications of lime, say 1000 lbs. per acre, every five or six years, than to put on heavier applications less frequently. This is the general rule in the Hawaiian Islands, larger applications being only made on a few plantations possessing a distinctly sour soil with much organic matter. However, some heavy clay adobe soils have been treated there with success with as much as fifty tons of coral sand to the acre; this procedure recalls the system of *marling* once so prevalent in English agricultural practice.

A point of very great interest in connection with cane growing and one which has not, so far as the writer is aware, been thoroughly investigated, is the lime : magnesia ratio best suited for the cane. For cereal crops generally, for rice, and for such as have a large leaf development, evidence has been brought forward by Loew[11] and his pupils that the lime should be in excess of the magnesia in proportion from 1·5 to 2 times as great. In the absence of any evidence to the contrary it may perhaps be taken that a similar ratio holds for the cane. That an excess of magnesia has a deleterious effect on the cane has been shown by Eckart,[12] who irrigated cane in tubs with both lime and magnesia chlorides, and found a much better growth when the lime was in excess of the magnesia than when the quantity of these two bodies was nearly the same.

Quite recently Loew[13] in Porto Rico has gone further into the subject in special reference to the cane ; in that island he has found the soils containing an excess of magnesia over lime. He quotes an instance of a cane soil suffering from acidity, stiffness and an excess of magnesia over lime where an application of 3000 lbs. lime per acre increased the yield of cane 57 per cent. He also writes : " The most favourable ratio of lime to magnesia in the soil for cane will very probably be as 2-1, if both are present in an equal state of availability. This can be inferred from experiments with maize by Bernadini."

The hypothesis of Loew, though carefully elaborated, is not accepted by many agronomists; it has been followed up chiefly in Japan by Aso and others. The lime-magnesia ratio must apply to the soil water or to readily soluble forms in the soil; a hydrochloric acid soil extract showing an excess of magnesia over lime would not be sufficient to condemn a soil on Loew's hypothesis. It is of interest to note that in some Demerara soil water, Harrison[11] has found that with sulphate of ammonia manuring the molecular ratio of calcium-magnesium was 1 : ·77 ; with nitrate of soda manuring it was 1 : 1·52, and with no manuring 1 : 2·40, and with no cultivation 1 : 2·57.

Yields of cane had become very deficient in the second and third cases but Harrison does not commit himself to attach any special significance to these ratios.

Distinction between Forms of Nitrogen.—Nitrogen is contained in manures as nitrate, ammonium salts, or as organic nitrogen ; these differ in their effect as regards ' availability.' It was formerly held that the plant absorbed nitrogen as nitrate ; latterly it has been clearly shown that ammonia salts may be directly assimilated. The organic forms of nitrogen have first to be acted on by soil organisms before they are of use to the plant, and hence they are not so rapidly available as nitrate or ammonia salts; cyanamide, too, is not at once available, and has to be acted on by soil organisms, but field experiments have shown that this substance has a high

order of availability. Of the organic forms of nitrogen Stubbs ranks castor pomace first, followed by dried blood and fish scraps.

Choice of Nitrogenous Manures.—As a general principle it has become accepted that sulphate of ammonia is the better material to use on soils containing a high percentage of calcium carbonate, since in such soils conditions are generally favourable for nitrification. On the other hand it is believed that in the absence of this body or on soils which are of an acid reaction that nitrate of soda is the preferable source. The idea, however, that nitrification is essential to the assimilation of nitrogen by plants must now, however, be definitely abandoned, as a whole series of experiments, initiated in 1887 by Pitsch and terminating with those of Miller and Hutchinson in 1909, have shown conclusively that plants can assimilate ammonia compounds directly.

The long continued application of ammonia salts to certain soils may result in an acid reaction therein with consequent sterility; such a result has been observed in light sandy soils at the Woburn Experimental Station. On the other hand, the long application of sodium nitrate may result in the deflocculation or puddling of the clay of soils, rendering them mechanically quite unfit for cultivation.

So far as tropical cane experiments and experience go the mass of evidence seems to be divided; but Harrison[14] is, however, of opinion that the heavy clay soils of British Guiana have benefitted rather than not by the long continued application of ammonium sulphate; this he is inclined to attribute in part to the alkaline nature of the sub-soil water. In Java too, sulphate of ammonia forms the source of available nitrogen. In the Hawaiian Islands nitrate is extensively used as a stimulant, though ammonia salts form a part of the high grade fertilizers also used; in Egypt and in Mauritius, nitrates are also extensively employed.

The organic forms of nitrogen are used with a different object to the more readily available, and their use as the sole source of nitrogen seems confined to Louisiana, where the simultaneous production of cotton seed meal may account for this preference.

At the moment of writing nitrate of lime is being extensively advertised, and this material may well become the most efficient source of nitrogen for the cane, but experiments with it are as yet imperfect.

Specific Action of readily available Nitrogen.—The action of ammonia as an early cane manure is thus explained by Geerligs:— Its application causes the sap to rise in the cane; the leaves are unable to elaborate this sap, and consequently the development of the undermost buds is forced (tillering or suckering); the number of canes in a stool is thus increased; it is essential that favourable weather follow this forcing, else the young shoots will wilt and die.

Choice of Phosphatic Manures.—All phosphates when applied to soils are fixed, and rendered insoluble; the *rationale* of the use of a soluble superphosphate, as opposed to the use of an insoluble phosphate, is that the solution of phosphoric acid is precipitated within the soil in a much finer state of division than can be obtained by grinding an insoluble phosphate, and mechanically ploughing it into the soil. Dependent on the type of the soil, the phosphoric acid will be precipitated within the soil as phosphate of lime, or iron or alumina. The former of these bodies is available to the plant, the latter is not; hence it is an axiom in manuring that superphosphates are suitable for calcareous soils or such as contain a considerate proportion of lime carbonate. On heavy clays such as constitute the cane lands of British Guiana superphosphates are contraindicated. On such soils basic slag is the form of phosphatic manure from which benefit is to be expected. It has been shown by many experiments that on clayey and peaty soils, where an alkaline base is required to neutralize the nitric acid formed by soil organisms, this form of phosphoric acid gives the best results.

Artificial Manures.—The properties of the manures occurring in commerce are briefly mentioned below :—

Sulphate of Ammonia.—The pure body contains 21·21 per cent. nitrogen, and as found on the market contains about 20 per cent. nitrogen.

Nitrate of Soda.—This material is extremely hygroscopic. The pure body contains 16·5 per cent. nitrogen, the commercial body containing about 4 per cent. of impurities; these impurities are in English commerce grouped together under the peculiar term of *refraction.*

Nitrate of Potash.—The pure body contains 13·8 per cent. nitrogen, and 46·5 per cent. of potash; it is but seldom used as a manure, the supply being devoted to other purposes; in an impure form it however finds its way to Mauritius from India, and being of local occurrence is used to a certain extent in Egypt.

Seed Cake Manures.—The refuse of seeds, &c., that have been crushed for oil, comes into the market in large quantities as manure. The plants that most largely contribute are cotton, flax, castor oil, cocoanut; their composition of course varies with the origin. In general these manures can be used only in the country of their origin, drawbacks of freight prohibiting their more extended use. Some analyses of these materials, collected from various sources, are given below :—

	Nitrogen per cent.
Ground nut (*Arachis hypogaea*)	4·06 – 7·94
Kapok meal (*Eriodendron anfractuosum*)	4·40
Castor cake (*Ricinus communis*)..	4·20
Coconut meal (*Cocos nucifera*)	3·62
Cotton seed meal (*Gossypium sp.*)	7·00
Chinese bean meal	6·96
Soja cake (*Soja hispida*)	6·12

Cotton seed cake is largely used in Louisiana, and the other forms of organic nitrogen are used to a certain extent in Java, where they form products of the country ; some quantity of these materials also finds its way from India to Mauritius. The refuse of indigo factories is also used in Java, and in Mauritius the refuse from aloe fibre factories.

Dried blood, as it comes on the market, contains from 10 per cent. to 16 per cent. of nitrogen.

Fish scrap is of very variable composition, containing from 5 per cent. to 8 per cent. nitrogen, and from 5 per cent. to 7 per cent. phosphoric acid.

Tankage is the residue from packing houses, and is of variable composition ; as it contains considerable quantities of bone it is also a phosphatic manure. It is similar in action and composition to fish scrap.

Guano.—The original Peruvian guano has long been exhausted, and the guanos now on the market are of recent origin. They differ much in composition from those of long accumulation. Some bat guanos contain an extraordinarily high amount of nitrogen, reaching up to 30 per cent.

Cyanamide is a synthetic compound of the formula $CaCN_2$; it is sold under the name lime nitrogen, German nitrate, or even as lime nitrate, from which it must be carefully distinguished ; as it appears in commerce it contains about 20 per cent. of nitrogen.

Nitrate of lime is manufactured and put on the market as a basic nitrate of composition $Ca(OH)NO_3$. It contains about 12 per cent. of nitrogen.

Gypsum.—This material is sulphate of lime, and, in a sense, can not be regarded as a manure ; it acts indirectly as a source of potash, which it sets free in soils ; it is also used as a corrective of soil alkalinity.

Bone manures contain from 4 per cent. to 6 per cent. of nitrogen, and from 40 per cent. to 50 per cent. of phosphate of lime ; this form of manure is sold as half-inch, quarter-inch, or as bone meal or dust, and is frequently steamed to remove the fats. The nitrogen is of little availability, and the phosphates, unless the bones are finely ground, are but slowly assimilated.

Mineral phosphates contain from 25 per cent. to 35 per cent. of phosphoric acid, and are occasionally used without previous treatment intended to render the phosphoric acid soluble.

Superphosphates usually contain about 20 per cent. soluble phosphoric acid, and in the form known to the trade as ' double superphosphate ' up to 40 per cent. to 50 per cent. They are prepared from mineral phosphates by the action of sulphuric acid.

Basic slag is the material obtained as a waste product in the ' basic ' process of steel manufacture ; it usually contains from 15 per cent. to 20 per cent. phosphoric acid, and from 40 per cent. to 50 per cent. of lime, a portion of which exists as free lime.

Reverted phosphate is the name given to a form of lime phosphate insoluble in water, but soluble in ammonium citrate solution, and which is valued at as high a figure as water soluble phosphoric acid. Superphosphates have a tendency on storage to pass into 'reverted phosphate,' and this material is manufactured and sold under the name of 'precipitated phosphate,' containing from 35 per cent. to 40 per cent. of phosphoric acid soluble in ammonium citrate.

Potash manures.—Potash is applied in cane-producing countries as pure sulphate containing about 48 per cent. of potash ; the chloride is also occasionally used. Kainit and other crude salts find a limited use in mixed manures.

Practice of Cane Manuring in different Countries.—

In Java and also in Demerara readily available nitrogen, chiefly in the form of ammonium sulphate, is to a large extent the only artificial manure applied. In Java it is claimed that the rotation there followed puts on the soil a sufficiency of other elements of plant food for the cane crop ; this is largely due to the water used in growing the rice holding in suspension a large quantity of silt, which is deposited on the land.

In Demerara it is also frequently the custom to apply up to 10 cwt. of basis slag phosphate to the plant canes, especially if analysis by Dyer's citric acid method shows a deficiency in this element. On the heavy clay soils it is exceptional to find a deficiency of potash, notwithstanding the heavy drain made on this element by the continuous crop of cane.

In Hawaii, where the largest yield of cane is obtained, relatively enormous quantities of manure are employed ; nitrate of soda is employed largely on the irrigated plantations in the districts of little rainfall, and this material, as well as sulphate of ammonia much less frequently, is used in the spring of the second growing season ; the application reaches up to 400 lbs. per acre.

In the Hawaiian Islands the climatic conditions are such that it is possible to obtain a period of growth from planting to harvest up to 24 months ; hence there are two growing seasons and the application of manures before each has been found to be very beneficial. The practice is generally to use mixed fertilizer in the first growing season and nitrate in the second.

In that district also a cold spell is annually encountered, when a check to and *yellowing off* of the cane occurs ; this is probably due to a cessation of the activities of the nitrifying organisms in the soil. It has been found by experience that the application of nitrates at this time has a very beneficial effect on the growth of the cane.

In addition a complete fertilizer containing on an average 7 per cent. to 10 per cent. each of nitrogen, phosphoric acid and potash is applied ; the

proportions of these ingredients are altered to correspond with the analysis of the soil. Up to 1000 lbs. per acre of such a fertilizer may be applied, although 600 lbs. is a more usual dressing. Basic slags are but little, if at all, used.

In Mauritius and Bourbon large quantities of pen manure were (previous to the extended use of mechanical traction) employed, and the plant canes seldom received any other fertilizer. To ratoon crops a complete mixture, similar to that quoted above as used in Hawaii, is employed but in a much smaller quantity.

In Louisiana, chiefly owing to its local production, cotton seed meal forms the chief source of nitrogen, and superphosphate forms the source of phosphoric acid. Owing to the abundance of potash in the soil this element is seldom necessary, and its action in retarding maturity is a reason against its use in such a climate.

In Egypt nitrate of soda is the chief source of readily available nitrogen, applications being made to the young cane after an irrigation. The Nile water used in irrigation brings into the soil a certain quantity of plant food, and the rotations followed also reduce the necessity for such heavy dressings of manure as are used elsewhere. A peculiar manure and of small value, collected from the refuse of old villages and known as 'ruins manure,' is also used by the fellaheen planters, as well as dove dung, to which a quite fictitious value is attached.

In Barbados and other islands of the British West Indies pen manure forms an important source of plant food.

The Ash of the Cane.—In common with other economic plants, the ash of the cane has been subjected to numerous analyses chiefly carried out with the object of determining the demands made on the soil, and of constructing an agricultural balance sheet. The earliest of these analyses are those due to Stenhouse of canes from British Guiana and the West Indies; later analyses are those due to Bonâme[15] in Guadeloupe, to Maxwell[16] in Hawaii, to van Lookeren Campagne, and to Kramers in Java.

While there is no lack of material, the discussion of these results is beset with enormous difficulty. In the first place a definition is required of *the ash of the cane;* that is to say, does the term include the ash of the entire plant, or of the stalk only? Secondly, the amount and composition of the ash varies with the age of the cane, as is very clearly shown in the analyses due to Rouf and already quoted. Thirdly, there is the effect of climatic variation. Fourthly and finally, there is the question of the reliability of the analyses; that is to say, under equal conditions can consistent results be obtained? This last point has been gone into very fully by Eckart[9], who in duplicate experiments in successive seasons failed to find any valuable correspondence

between the results. The experiments in question were planned by Maxwell to determine the relative demands made on a soil by different varieties ; the weight of cane, including its stalks and waste products and the weight of ash therein was determined ; this observation combined with the anaylsis of the ash gave data for the construction of a detailed balance sheet. The results of a second season's determination gave, however, results quite at variance with those obtained in the first. I do not then think that any very useful purpose will be served by quoting in full these and similar analyses.

Reviewing however the analyses due to Maxwell, Eckart, Bonâme and others, the following statements can be made :—

(a.) By far the greater part of the ash of the entire plant is contained in the leaves, tops and waste matter ; such is especially the case in Hawaiian, as compared with Guadeloupe, canes. This relation will be profoundly affected by the personal equation of the investigator as well as by conditions of growth and period of harvest.

(b.) In the leaves and waste matter the predominant element is silica, with potash second in amount ; in the stalks the position is reversed.

(c.) The lime and magnesia are present in approximately equal amounts, sometimes one and sometimes the other being in excess ; the same statement is true of phosphoric acid and sulphuric acid.

(d.) The quantity of nitrogen and ash contained in the entire Hawaiian grown plant, per ton of stalks, is much greater than in the Guadaloupe canes ; the yield per unit area is much greater in the former than in the latter, the growth in Hawaii having taken place under heavy manuring, aided by copious irrigation. This does not imply a greater drain on the soil, since the leaves and waste matter are returned to the soil and most of that carried away to the mill in the stalks is still available.

(e.) The ash of the entire plant lies within the following limits :— Silica 45 per cent. to 50 per cent. ; potash 15 per cent. to 20 per cent. ; lime 4 per cent. to 6 per cent. ; magnesia 4 per cent. to 6 per cent. ; phosphoric acid 2 per cent. to 5 per cent. ; sulphuric acid 2 per cent. to 5 per cent. ; in some instances comparatively large amounts of chlorides have been found,

The Amount of Ash contained in a Crop of Cane.— In view of what has been written above, it at once follows that any attempt to obtain a general balance sheet of plant food demands is fallacious ; dependent on which series of analyses is taken, results varying several hundred per cent. may follow. Thus in one extreme case in Hawaii 94 lbs. of ash were obtained per short ton of stalks, a figure falling to 15 lbs. in one of Bonâme's trials in Guadeloupe.

The Ash of a Plant in Relation to Manuring.—It has been thought that the analysis of the ash of a plant and the agricultural balance

sheet would give information as to the proper combination of manures to apply ; this idea demands that for any plant there is one particular ash analysis which is most suited for it. The variation, however, is so great that no 'best ash' for the cane can be obtained, and this captivating hypothesis breaks down on subjection to scrutiny, or rather is not supported, as regards the cane, by sufficient evidence. It is conceivable, however, that an ash analysis showing a low proportion of, say, lime might point to a deficiency of available lime in the soil ; on the other hand a deficiency of lime in the soil might be reflected in small crops rather than in a low percentage of lime in the ash.

Connected with this subject is the " Analysis of the Soil by Means of the Ash "; this point has been recently studied by Hall[18], who thus summarizes his results, obtained of course in a temperate climate (England) but none the less generally applicable :—

1. The proportion of phosphoric acid and of potash in the ash of any given plant varies with the amount of these substances available in the soil, as measured by the response of the crops to phosphatic or potassic manures respectively.

2. The extent of the variation due to this cause is limited, and is often no greater than the variations due to season, or than the other variations induced by differences in the supply of non-essential ash constituents—soda, lime, &c.

3. The fluctuations in the composition of the ash are reduced to a minimum in the case of organs of plants, which, like the grain of cereals or the tubers of potatoes, are manufactured by the plant from material previously assimilated.

4. The composition of the ash of the cereals is less affected by changes in the composition of the soil than is that of root crops like swedes and mangels.

5. The composition of the ash of mangels grown without manure on a particular soil gives a valuable indication of the requirements of the soil for potash manuring. Similarly the phosphoric acid requirements are well indicated by the composition of the ash of unmanured swedes, though in this case determination of the citric acid soluble phosphoric acid in the soil gives even more decisive information.

6. Pending the determination of phosphoric acid and potash 'constants' for some test plant occurring naturally on unmanured land, the interpretation of soil conditions from analyses of plant ashes is not a practicable method by which chemical analysis of the soil can be displaced.

The Utilization of Waste Products as Manure.—In order to estimate the quantity and distribution of the ash and nitrogen brought into a factory, the writer made the analyses detailed in the Tables below, for a factory working up to 50,000 tons of canes. The process used in the factory was dry double crushing and simple lime defecation ; no sulphur or phosphoric acid was used. In Table I. are given analyses of the ash of various products ; in Table II. the total amounts entering the factory per 1000 tons of cane ; and in Table III. the distribution of the nitrogen and the constituents of the ash over all the factory products, the amount in the canes being put equal to 100. Inspection of these tables will show that on this particular estate the amount of potash in the canes was abnormally high, and that of the lime equally low, the phosphoric acid being present in moderate quantity.

TABLE I.

	Juice.	Megass.	Canes.	Filter Cake.	Sugar I.	Sugar II.	Lees.	Yeast Deposit.
Ash per cent.	·67	1·00	·77	11·55	1·15	3·54	1·79	..
Lime	1·22	2·41	1·33	17·96	4·73	4·64	6·53	..
Magnesia	4·72	2·92	3·96	5·11	2·70	2·95	3·98	..
Potash..	40·84	16·82	31·23	1·07	39·54	37·26	41·82	..
Soda..	2·18	1·53	1·92	Trace	1·90	1·63	2·32	..
Phosphoric acid	4·97	3·25	4·15	16·17	2·74	3·67	1·61	..
Sulphuric acid	15·49	6·22	11·72	1·71	22·60	23·42	20·88	..
Nitrogen*..	·052	·028	·045	1·50	..	..	·101	1·96

(Column group label at left: Per cent. of Ash.)

* Per cent. on actual material.

TABLE II.

	Total Ash	Lime.	Magnesia.	Potash.	Soda.	Phosphoric Acid.	Sulphuric Acid.	Nitrogen.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Canes	17300	295	690	5380	330	740	2040	1010
Used in manufacture .	..	850	..	..	..	..	590	80
Juice	10270	125	480	4190	220	510	1590	810
Megass	7030	170	210	1180	110	230	440	200
Filter Cake..	1830	350	95	20	..	310	30	230
Sugar I.	1620	80	43	640	20	45	370	..
Sugar II.	690	30	20	250	10	25	160	..
Lees..	7600	460	300	3180	180	120	1560	440
Yeast deposit	..	..	..	..	..	..	..	195

(Column group label at left: Per 1000 tons of cane.)

TABLE III.

	Ash.	Lime.	Magnesia.	Potash.	Soda.	Phosphoric Acid.	Sulphuric Acid.	Nitrogen.
Canes	100	100	100	100	100	100	100	100
Used in manufacture .	..	288·0	..	..	..	..	28·9	7·9
Juice	59·4	42·4	69·6	78·0	66·6	68·9	77·9	80·2
Megass	40·6	57·6	30·4	22·0	33·3	31·1	21·5	19·8
Filter cake	10·6	118·6	13·8	0·4	..	41·8	1·5	22·8
Sugar I.	9·3	26·0	6·2	11·9	6·1	6·1	18·1	..
Sugar II.	3·9	10·2	2·9	4·6	3·0	3·4	7·8	..
Lees	43·9	155·8	44·1	59·1	54·1	16·2	76·5	43·5
Yeast deposit	..	..	..	..	..	..	..	19·3

The amount of plant food lost in the factory operations is that carried away in the sugars together with the nitrogen lost in the combustion of the megass; roughly speaking the sugars carry away 10 per cent. of the ash constituents contained in the canes, and 20 per cent. of the nitrogen is lost with the megass. In accordance with what has already been written, this would represent a loss only half as great when referring to the whole crop—cane and trash.

Although nearly the whole mineral and nitrogenous matters of the crop are retained in the factory by-products, their economical return is a matter of no inconsiderable difficulty. The filter press cake, rich in nitrogen and phosphates, is in a form easily handled, and its application presents no difficulty. No loss of nitrogen need be feared if it be necessary to store the press cake over lengthy periods, as the annexed analyses show. These analyses of press cake from the same factory were made by the writer to test this point:—

	Nitrogen per cent. on dry matter.
Fresh press cake	1·173
Press cake 12 weeks old, exposed to weather	1·184
Press cake, 100 weeks old, stored under cover	1·189
Press cake, 100 weeks old, exposed to weather	1·172

The megass ashes, rich in phosphates and potash, are also readily applied; in this material the potash is in great part soluble in water, and if exposed to rain the most valuable constituent is leached out and lost.

In the analyses given above, a material is referred to under the name 'yeast deposit'; by this is meant the sedimentary deposit of dead yeast cells occurring in the fermentation vats. For the particular distillery on which this estimate is based, 2·5 gallons of a thick sludge of yeast cells were produced per 100 gallons of wash; one gallon of this sludge contained 1·43 lb. solid matter and ·196 lb. nitrogen, or 13·70 per cent. on the solids. There is here a source of a concentrated nitrogenous manure which is often run to waste. The deposit might be collected and applied in its natural condition or passed through filter presses and obtained as a cake carrying 50 per cent. to 60 per cent. water and 6 per cent. to 7 per cent. nitrogen. Per 1000 gallons of wash about 50 lbs. of such cakes would be obtained, and per 1000 acres about 20 tons would result.

The material which offers the greatest difficulty with regard to its economical return is the lees or distillery refuse; the following methods suggest themselves.

1. Concentration to small bulk.

2. Destructive distillation and incineration of residue, collecting the distillates and recovering the phosphates, and especially potash, in the residue.

3. Irrigation of cane fields with lees.

4. Precipitation with lime and collection of the resulting precipitated phosphates and nitrogenous matter.

5. Collection of the lees in ponds and subsequent excavation of the 'lees mud,' and application as manure.

The concentration of the lees to a density of 1·25 would mean an evaporation of 90 per cent. of their weight, and even if performed in an efficient multiple evaporator would entail great fuel consumption in value over and above the value of the product obtained. The same obstacle stands in the way of the incineration of the residue, although certain beet sugar factories which work up their molasses for beet spirit treat the 'Schlempe,' or 'vinasse' (as the lees are termed) for collection of potash residues.

Lees irrigation has been tried, and there is much to be said in favour of this method of conservation of valuable plant food. Experiments in Scotland have shown that the refuse from whisky distilleries is not, at any rate in the quantities in which it would be applied, injurious to vegetation. Such a scheme was once actually in operation in Demerara, but, the distillery being burnt down and not re-erected, it was not continued.

Lees when treated with lime give a copious precipitate; it was found by direct experiment that to completely precipitate 1000 gallons, 150 lbs. of commercial lime were necessary. After treatment with lime, lees that contained originally ·01040 lb. nitrogen per gallon now contained ·00406 lb., so that over 60 per cent. of the nitrogenous matter was recovered in the precipitate. On filtration a sludge was obtained, in volume about 15 per cent. of the lees treated; when dry this material contained 3·82 per cent. nitrogen. To treat lees in this way would require no expensive outlay, but the method would still let the potash run to waste; per 1000 tons of cane, 4 tons more or less of a filtered sludge carrying 50 per cent. water would be obtained, the material containing about 1·9 per cent. of nitrogen.

The present method of utilizing lees is to run them into a pond or blind trench, which is periodically excavated and the material obtained, a soft black mud, carried to the fields; this method, while allowing a considerable loss in drainage, is expensive owing to the bulkiness of the material. Where the estate has a large quantity of cattle, and where the pen manure is systematically collected, the lees can very well be absorbed by the soiled litter.

In many districts a distillery is not an adjunct of the sugar house, and instead of having lees to dispose of, molasses form the refuse of the factory. In Hawaii the molasses are sometimes returned to the soil in irrigation water, and in Mauritius they often find their way to the manure heaps. Another way of utilizing the molasses is to feed them to the plantation stock, and recover their manurial value in the excreta.
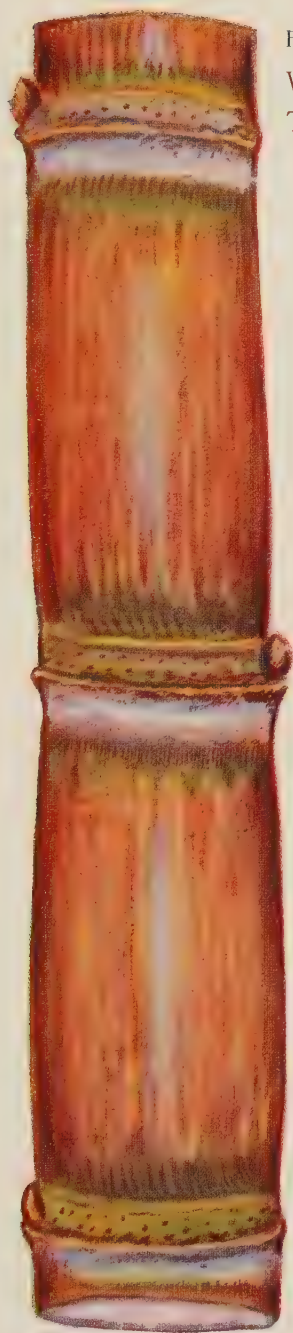
FIG. 13.
WHITE
TANNA.

$\frac{3}{4}$
SIZE

PLATE V

In a Sugar Plantation there is little Drain on the Soil.— A sugar estate ships only carbon, hydrogen and oxygen, none of which are obtained from the soil; the whole of the nitrogen and ash is contained in the by-products—leaves, tops, press cake, molasses, &c.,—and if these are returned, the fertility of the soil should remain permanently unimpaired. This generalization requires some modification. Few estates make white sugar, and the raw sugars contain some part of the ash and nitrogen; in other cases molasses are sold off the estate, and in the combustion of the megass the nitrogen and some of the potash are lost; loss of the first-named material also occurs in burning off trash. To these causes of soil impoverishment must be added that due to drainage waters; notwithstanding, the agricultural cycle of a sugar estate is very different from that of a farm where grain, roots, milk and live stock are removed.

Bacteria in Relation to the Soil.—This subject, which is one of the most important problems of the day, can only be touched on in bare outline. In the first place, organic matter buried in the soil is acted on by both bacteria, and by fungi; a product (humus), richer in carbon and poorer in oxygen than the original material, eventually results. In the presence of air this action proceeds faster, and is more complete, than in its absence; hence the availability of organic matter, cane trash for example, and of manures such as cotton seed cake, is more rapid in well tilled than in unworked soils; similarly, in stagnant soils, there is an accumulation of organic matter, as in bogs and peaty soils. The products formed by the action of the soil organisms are of an acid nature, and unless some base, such as calcium carbonate, is present in the soil to neutralize the acids formed, bacterial action eventually ceases, and what decay then occurs is due to fungi; in this case, too, the decomposition is not so complete, and there is a tendency to the accumulation of organic matter, in the soil. The form in which this organic matter occurs may not be of benefit to plant life; soils formed under these conditions may contain large quantities of nitrogen, and yet be unproductive, until by tillage and aëration, such a bacterial flora is obtained that the supply of nitrogen is offered in an assimilable form.

A number of years ago a preparation of certain micro-organisms was put on the market under the name of *alinit*; it was stated to consist of a pure culture of an organism known as *Bacillus ellenbachensis*, and to it was attributed the property of fixing nitrogen from the air; it was observed to benefit soils containing much humus, and to be beneficial in conjunction with slow acting nitrogenous manures; its action was probably due to its initiating bacterial action on soils where the organisms, associated with the decay of organic matter, were absent. The use of this preparation has now merely an historical interest.

The possibility of the utilization of the nitrogen of the atmosphere by the higher plants forms one of the world's classical polemics.* It is at the present

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* The fixation of nitrogen by the leguminosæ is discussed under a separate caption.

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moment accepted that, through the agency of certain bacteria, the nitrogen of the air becomes fixed in the soil, and thus indirectly becomes available to the higher plants; the organisms that have been most studied in this connection are the *Clostridium pastorianum* and the *Azotobacter chroococcum;* the latter is of cosmopolitan distribution, 'varieties' from different parts of the world showing only minor differences; a supply of calcium carbonate is probably essential to its development, and the amount of nitrogen fixed is correlated with the quantity of carbohydrate present. In this connection, and in special reference to the cane sugar industry, Ebbels[17] has indicated the use of molasses as a source of carbohydrate. Although it is now certain that nitrogen in the form of ammonia can be assimilated by some higher plants, yet it is as nitrate that the greater proportion is taken up; the working out of the cycle, whereby the plant takes up its nitrogen, is due to Schloesing and Muntz, to Warrington, to Frankland, and especially to Winogradsky. As a result of their investigations it has been established that the formation of nitrates takes place in two stages; two types of organisms are employed in the first stage, one, classified as *nitrosomonas* peculiar to the old, and the second as *nitrosococcus* occurring in the new world. These organisms convert ammonia salts into nitrites; the conversion of the nitrite into nitrate is effected under the influence of an organism called *nitrobacter*, which is cosmopolitan. The factors influencing the activity of these organisms are briefly as under :—

1. The limits of activity are 5°C. and 55°C., with an optimum temperature of 37°C.

2. Their activity is diminished by the presence of much organic matter, and by the presence of alkaline chlorides and carbonates.

3. A base is necessary to neutralize and combine with the acid formed ; the most efficient base is calcium carbonate, but magnesia carbonate, and the zeolites present in clay may also serve.

4. A supply of oxygen, and of carbon is necessary ; the latter may be derived from carbonates, or from the carbon dioxide of the air.

5. A supply of water is essential, but not an excess, which is actually harmful.

6. Absence of direct sunlight.

From the above it is seen that nitrification, and hence plant growth will proceed best in a well tilled, well aërated, well drained soil, at a temperature of about 37°C. and in the presence of a supply of calcium carbonate.

Conversely to the formation of nitrates, a degradation of these bodies eventually to gaseous nitrogen occurs. This process known as denitrification takes place under the influence of a variety of organisms, and the favour-

able conditions are the reverse of those aiding nitrification, that is to say, it proceeds in the absence of air, and in the presence of an excess of water and of organic matter ; hence it occurs in badly tilled, unaërated waterlogged soils. Dentrification has also been noted to occur when fresh stable manure, new dung or even finely chopped straw is added to the soil, so much so as to depress the yield below that obtained when no manure is added to the soil. In addition, the combined use of stable manure and of the readily available forms of nitrogen has been contraindicated ; this action is perhaps due to the introduction of large numbers of denitrifying organisms, and to the inhibiting effect of large amounts of organic matter on the nitrifying organisms. However, the experiments of Wagner and others, from which these conclusions were drawn, were not made under conditions consonant with ordinary agricultural practice, and contain nothing to warrant any fear of harm resulting from the well-advised return to the soil of well-rotted stable, &c., manure as usually practised as a standard agricultural process.*

Green Manuring.—Green soiling or green manuring is a practice which has been carried on for generations past. In Europe the method employed is to sow a catch crop of some quickly growing plant between the harvest of the one and the seed time of the succeeding crop ; the catch crop is ploughed into the soil and acts as a green manure to the following crop. The principles of this practice are as follows. It had been known for a large number of years that leguminous crops (beans, peas, clover, &c.), although they contained large amounts of nitrogen, did not respond to nitrogenous manurings, and even frequently gave a smaller crop when manured with nitrogen than when unmanured. It was eventually established by Atwater in America, Marshall Ward in England, and Hellriegel and Wilfarth in Germany, about 1886, that leguminous plants are able to absorb nitrogen from the air. The absorption is not made directly by the plant, but by the agency of bacteria. If the roots of a leguminous plant be examined, there will be found attached to its rootlets a number of wart-like excrescences the size of a pin's head and upwards. These bodies, which are termed nodules, on being crushed and examined under the microscope, are found to consist of countless numbers of bacteria ; these bacteria, living in symbiosis or commensalism with the host plant, supply it with, at any rate, a part of its nitrogen.

If then leguminous plants be sown and allowed to reach maturity, and then be ploughed into the soil, there is placed in the soil a large amount of nitrogen obtained from the air.

Green manuring as an integral part of cane cultivation is practised most intensively in Louisiana and Mauritius, and to a limited extent in Hawaii.

*For more detailed discussions reference may be made to Hall's *The Soil*, and Hilgard's *Soils*, which the writer considers the best books, in English, that deal with general agriculture.

In Louisiana, after plant cane and first ratoons have been grown, the land is sown with cow peas (*Vigna unguiculata*), using from one to three bushels per acre; in August or September the peas are ploughed in and cane planted in October. According to Stubbs, the crop of cow peas above ground is often removed as fodder for cattle, planters who do this holding that the roots supply sufficient nitrogen for the crop, but Stubbs states that when the green crop is ploughed in an average increase over plant and first ratoon cane of 7·42 tons per acre is obtained over that obtained when the green crop is removed for fodder; the amount of nitrogen afforded by a crop of cow peas is, according to Stubbs, about 100 lbs. per acre.

In Mauritius there are four crops used as green manures :—

1. The Pois d' Achéry (*Phaseolus lunatus*).
2. The Pois Muscat.*
3. Pigeon Pea (*Cajanus indicus*).
4. Indigo sauvage (*Tephrosia candida*).

The first two are pea vines growing in dense thick matted masses. The pigeon pea is a shrub growing to a height of four or six feet; the indigo sauvage is also a shrub, but of rather less robust habit. The system generally followed is to grow cane up to third ratoons; the land is then planted with one or other of the above crops, the time during which it is rested under the leguminous crop being from one to three years, dependent on the land available. Where land sufficient for one year's rest only is available, the pois muscat is generally grown; the pois d' Achéry is generally allowed to grow for two years, and the pigeon pea and indigo for three or four. All four crops are planted from seed, which is sown about 15 to 18 inches apart. Where no land can be spared to rest, one or other of the above crops is occasionally sown between the rows of cane, and after a few months' growth cut down and buried.

Although the benefits of green manuring are undoubted, it must be remembered that the expenses connected with it are not small, and very possibly where virgin soil can be had in abundance it may for a time be more economical continually to take in new land than to renew the fertility of old. The benefits of green manuring are most pronounced on estates which have continually to plant on the same soil; such estates are found in Mauritius, Barbados, and other small islands.

Besides placing in the soil a supply of readily available nitrogen, green manuring has other advantages.

* In *Sugar and the Sugar Cane* I, in error, stated that the Pois Muscat was *Mucuna atropurpurea;* the Pois Muscat is, I now find, economically identical with the Velvet Bean of Florida classed as *Mucuna puriens var utilis;* the only difference is that the Pois Muscat has a black and the Velvet Bean a mottled seed; this statement is based on the studies of Bort, in Bull. 141, U.S.D.A. Bureau of Plant Industry, where the Velvet Bean is redescribed as *Stizolobium deeringanum.*—(*N .D.*)

1. The advantages of a rotation are obtained.

2. The deep tap-roots of leguminous plants bring available plant food from the subsoil to the surface soil.

3. The ill effects of a naked fallow are avoided.

4. The interposition of a crop other than cane will act as a prophylactic towards fungus diseases and attacks of insects, for if the habitat of these parasites be removed for any length of time it must result in their diminution or disappearance from lack of food.

In certain quarters, notably in Mauritius, after land has been under leguminosæ for a time, it is prepared for cane cultivation again by burning off the green above-ground crop. This process would seem to destroy the very benefits to obtain which the green manure was planted. Planters who follow this system claim as good a result as when the green crop is buried, and point to the saving in expense. To obtain definite information as to this process the writer grew on small plots equal to $\frac{1}{500}$ of an acre crops of the *Phaseolus lunatus** and *Mucuna utilis*. The results calculated out to an acre were as below. The crop in both cases was six months between planting and harvesting, which was done when the seeds were ripe.

			Phaseolus lunatus. Kilos.	Mucuna utilis. Kilos.
Weight, dry matter,	in	green crop	1621	2522
,,	,,	beans	132	466
,,	,,	roots	123	80
Nitrogen	,,	in green crop	30·3	54·0
,,	,,	roots	1·2	·7
,,	,,	beans	5·6	16·7
Potash	,,	in green crop	42·0	46·5
,,	,,	roots	4·4	2·1
,,	,,	beans	1·2	9·5
Phosphoric acid	in	green crop	11·4	14·4
,,	,,	roots	1·1	·4
,,	,,	beans	·7	4·2

It will be seen that about 80 per cent. of the manurial value of the crop was contained in the green crop; if this is burnt off the nitrogen is lost, but the potash and phosphoric acid remain in a form readily available for the coming crop of cane. The economy of burning off the green crop and losing the nitrogen is comparable with the practice of burning off trash; in any case there is obtained a large amount of mineral plant food brought up from the subsoil. The high nitrogen content of the bean straw, and the possibility of using this material as bedding for plantation stock, and thus both conserving it and obtaining a pen manure rich in nitrogen, is worthy of notice.

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* Pois d'Archéry in Mauritius ; the 'Java' and 'Rangoon' beans of commerce.

Among other plants grown in tropical countries as green manure are *Sesbania aegyptica*, *Crotallaria pincea* and *C. laburnifolia*, *Phaseolus semierectus*, *Arachis hypogaea* (the earth nut), *Soja hispida* (the soy bean), *Dolichos lablab* (the bonavist bean), *Phaseolus mungo* (woolly pyrol), *Indigo tinctoria* (the indigo of commerce), and, in Hawaii, a variety of lupine.

The percentage of nitrogen in some of these plants is given below :[18]—

	Per cent. Water.		Per cent. Nitrogen.
Sesbania aegyptica	82·30	..	·68
Crotallaria laburnifolia	79·80	..	·70
Phaseolus semierectus	81·00	..	·52
Arachis hypogaea Plant	80·00	..	·58
Arachis hypogaea Fruit	—	..	2·76

Rotations.—Different crops have a predilection for different forms of mineral matter, and thus remove from the soil very different amounts of the different constituents of plant food, so much so that the ash of a crop may consist in general of one predominant constituent; by growing continually one and the same crop on the same piece of land there is then a tendency to exhaust one particular constituent. If, however, different crops be grown in rotation, an element of plant food which was removed in large quantities in one year is not absorbed to such an extent by the succeeding crop, and by the time the crop first in rotation is planted a second time a sufficiency of the particular material exhausted by this crop will have become available, due to the natural process of disintegration which soils are continually undergoing. As an example of such a rotation, the Norfolk system may be quoted; this is wheat, roots, barley, clover; the roots are consumers of potash, the wheat takes up phosphates, the barley absorbs silica, and the clover feeds largely on lime and magnesia.

It is especially to be noted in this rotation that the wheat follows the leguminous crop of clover; wheat is a crop that responds to a supply of nitrogen in this case in part provided by the root residues of the clover; the cane, too, demands, as is shown in the manurial trials quoted above, for its successful growth a supply of readily available nitrogen, and in certain districts a leguminous crop precedes the cane crop.

Cane growing districts may be divided into those where the cane forms the sole output of the soil, and those where it is alternated with other crops. Into the first category fall the districts of Cuba, the Hawaiian Islands, British Guiana, Trinidad, Fiji. In Java, Egypt and British India, a complete rotation is practised, and in Louisiana and Mauritius the cane fields are rotated with leguminous crops which are ploughed in.

In Egypt, on the lands controlled by the Daria Sanich, cane was grown for two years, preceded by a year's fallow; following on the cane crop corn and clover were grown; the cane itself was not manured, with the object of

obtaining a sweet cane.   Private owners follow a rotation of clover, wheat, cane (no ratoonage), and manure the cane heavily.

In Louisiana the general rotation is plant cane, ratoons, and cow peas (*Vigna unguiculata*) ploughed in as a green manure.

In Mauritius it is general to grow cane up to third ratoons, after which a green leguminous crop occupies the land for from one to four years.

In Java the following rotations are practised —

1. Cane, 'ground provisions,' rice, ' ground provisions,' rice, cane.
2. Cane, 'ground provisions,' rice, cane.
3. Cane, rice, 'ground provisions,' rice, cane.

In 'ground provisions' are included ground nuts, beans, maize, cassava, and yams.

Where the sugar cane forms the main crop in India, the following typical rotations, amongst others, are given by Mukerji[19] :—

Bengal.—High and light soils.   Rice (May to September); pulse or oil seed (October to March); jute (April to September); pulse or oil seed (October to March); rice (May to September); potatoes (October to February); sugar cane (February to February); rice (May to September); pulse (October to March), &c.

Punjab.—Dhainea (*Sesbania aculeata*) or sun hemp, (*Crotalaria juncea*), or cow peas (*Vigna unguiculata*) cut in bloom in August; potatoes (October to February); sugar cane (February to February), pigeon pea (*Cajanus indicus*) or rice; potatoes; sugar; sugar cane.

Whenever practised the absence of a rotation is a weak point in sugar cane culture; the rich fertile soils which are often met with in the tropics can for a number of years support a continuous unvaried crop, but eventually they must become barren.   In certain countries, as Demerara, where abundance of virgin soil awaits cultivation, proprietors can continually empolder new land and allow that which has become barren to lie fallow, and after a space of time, during which by the continued disintegration of the soil plant food has become available, again plant the old abandoned land.*

The effect of continuously growing cane on the same soil has not been, so far as the writer is aware, distinctly studied, but the following quotation from A. D. Hall[20] with reference to the Rothamsted wheat experiments seems broadly applicable also to cane culture :—

" Plot 10 has received an annual dressing of nitrogen only, in the shape of ammonium salts since the earliest dates of the experiments.   It will be evident from the curve showing the crop production that, despite this long continued use of a manure supplying but one element of plant nutrition, the crop has been wonderfully maintained.   Whereas the average production over the whole period is increased by the supply of minerals to the extent of 1·8 bushels, the nitrogen alone has produced an average increase of 7·6 bushels, the unmanured plot being taken as the standard

*See Note in *Appendix*.

in each case. The curve, however, shows that the production on this Plot 10 is declining, notwithstanding the great reserves of mineral plant food with which the soil started. At the present time also the crop on this plot presents a very unhealthy appearance, is very slow to mature, and is extremely liable to rust.

"We thus see that it is possible to grow a cereal crop like wheat, year after year, on the same land for at least sixty years without any decline in the productiveness of the soil, provided an appropriate manure be supplied to replace the nitrogen, phosphoric acid and potash removed by the crops. There is no evidence, in fact, that the wheat gives a smaller yield when following a long succession of previous wheat crops than when grown in rotation, although the vigour of the plant does not appear to be so great. The real difficulty in continuous corn growing is to keep the land clean; certain weeds are favoured by the wheat and tend to accumulate, so that the land can only be maintained clean by an excessive expenditure in repeated land hoeing. Notwithstanding all the labour that is put on the plots, the 'Black Bent' grass, *Alopecurus agrestis*, has from time to time become so troublesome that special measures have had to be taken to eradicate it and to restore the plots to a reasonable degree of cleanliness."

It does not seem altogether unreasonable to attribute in part the damage done by fungus and insect pests to the continual growth of cane on the same soil, as in this way the pests have a continuous habitat.

In discussing rotations it may not be out of place to refer to the **toxic excretion** theory; it was originally suggested by De Candolle that plants excreted a toxic substance which prevented the continual growth on the same soil, and in this way explained the benefits of rotations. After definite abandonment this idea has been revived, mainly by Whitney and Cameron, but its discussion lies altogether without the limits of the present text book.

Pen Manure.—In those countries which employ animal traction very large numbers of cattle and mules are kept for transport purposes, and large quantities of pen manure are produced annually, and it is remunerative to stall the cattle at night with sufficient litter, such as dry cane trash, to absorb their urine. In Mauritius great attention is paid to this source of manure. The method adopted is as follows.

The live stock of the estate, which may number from two to three hundred, are in great part kept in 'parcs,' which may be from fifty to a hundred yards square; a portion of the parc is often covered in to provide shelter in inclement weather. The whole area is covered with cane trash transported from the fields and used as bedding. During the whole year if the supply of labour is sufficient, the soiled litter is in a continual process of renewal and removal, the bedding being replaced throughout on an average once a week; on removal it is placed on stone platforms or in basins ten feet deep, both platforms and basins generally being about fifty feet square. The whole mass when completed is continually watered with fermented molasses and water or distillery refuse, and sometimes with dilute sulphuric acid; the drainings collect in

stone pits and are continually repumped over the heap of manure; the object of this is to rot the manure and at the same time to fix any volatile ammonia given off. In from six to twelve months the manure is considered sufficiently rotten to place on the fields, where it is applied at the rate of from ten to twenty tons per acre to plant canes only, generally at an age of three months; or occasionally the cane holes are filled with the manure and the tops planted on it.

The amount of manure made per animal per year is from fifteen to twenty tons where bedding is used, and where the dry dung only is collected, from two to three tons.

It is very often the case that manure making is forced, that is to say, more straw than necessary to absorb the urine and contribute to the comfort of the animal is brought in as bedding; the false economy of this proceeding is apparent, but its practice is not uncommon.

The composition of the manure varies within considerable limits; where a reasonable amount of bedding has been used, the percentage of nitrogen generally, in the writer's experience, lies between ·6 per cent. and ·8 per cent., falling to ·3 per cent. to ·5 per cent. where an excess of trash has been brought to the stables or pens; the potash and phosphoric acid do not seem to show any variation dependent on the amount of bedding used, both lying between the values ·2 per cent. to ·7 per cent.; these figures refer to manure with from 70 per cent. to 80 per cent. of moisture.

The expense of making pen manure is very considerable; the cost in Mauritius varies from two to five shillings per ton, a portion of which expense would be incurred in any case; the carting and application costs about one shilling per ton, making the total outlay from three to six shillings per ton. This expense is very considerable, and in general it may be said that where stock is kept on the estate it will pay to carefully conserve their excreta, but it will not pay to keep animals to make manure, or to force the production beyond its natural limits.

With the general increase in the size of estates and the consequent necessity for mechanical traction, pen manure is losing its importance, and its place is being taken by artificial fertilizers. The fertility of soils in districts, such as Barbados and Mauritius, over many generations is, the writer believes, to be largely attributed to the extensive and well ordered use of the pen manure manufactured on the estates. The modern tendency is to grow crops with the aid of irrigation and of the more concentrated artificial manures, and it largely becomes a question of the cost of the labour required to make and to apply the pen manure compared with that required for the purchase and application of the artificial manure. It is not yet known what will be the final effect on the soil in several generations of the modern practice.

REFERENCES IN CHAPTER VI.

1. *S. C.*, 257.
2. *S. C.*, 338.
3. *W. I. B.*, II., 6.
4. *S. C.*, 52.
5. *Bull. 9, Sta. Agron., Mauritius.*
6. *Bull. 16, Agric. H. S. P. A.*
7. *Bull. 29, Agric. H. S. P. A.*
8. *I. S. J.*, 66.
9. *Bull. 12, Agric. H. S. P. A.*
10. *Pamphlet 30, Imp. Dept. Agric., West Indies.*
11. *Bull. I., U. S. D. A.*
12. *Bull. 8, Agric. H.S.P.A.*
13. *Circular 12, Porto Rico Experiment Station.*
14. *W. I. B.*, IX., 35.
15. *Cultur de la Canne à Sucre*, p. 24.
16. *Jour. Agric. Science*, I., 87.
17. *Agricultural News*, July, 1908.
18. *Das Zuckerrohr*, p. 227.
19. *Encyclopedia of American Agriculture*, III., 108.
20. *An Account of the Rothamsted Experiments*, p. 40.

CHAPTER VII.

THE IRRIGATION OF THE CANE.

A very large proportion of the cane crop is produced partially or entirely under irrigation; thus irrigation forms an important factor in the Hawaiian Islands, in Java, in Egypt, in British India, and in Peru; a few estates in Mauritius are also irrigated. The West Indies, Louisiana, Fiji, Australia, and the island of Hawaii are districts which produce mainly under natural conditions. It is only in the Hawaiian Islands (the writer believes) that plantations have constructed and own independently their water supply; in the other irrigation districts the irrigation works are state-owned and controlled.

Unit of Measurement.—Irrigation water is measured as a volume flow per unit of time or as a depth per unit of area. In the first system the cubic foot second or '*cusec*' is the generally adopted English unit; this flow is usually referred to the acre; in the metric system the unit is a litre-second referred to a hectare. The acre-inch is the usual unit of depth measurement and this unit is equal to 101·5 tons, to 3652 cubic feet, to 22,736 imperial gallons, to 27,294 U.S. gallons, and to 103,130 litres. In the Hawaiian Islands, the plantation reckoning is in many million (U.S.) gallons per day, of which 1,000,000 are estimated as necessary for each 100 acres in cultivation.

Hawaii.—On the islands of Oahu, Maui, and Kauai the crop is almost entirely grown under irrigation. Irrigation was begun in Hawaii in 1907 and is now developing. The system followed is one of short furrow irrigation, the length of furrow being adopted to the nature of the soil. During the first crop the water runs along the cane row; in ratoon crops which are hilled up the water runs between the row.

The following data are based on a report of Maxwell[1] : —

During a period of growth of about 17 months the total water supplied to the crop averages about 100 inches. Reference to the table below will show that the young cane received less water than when more mature, but not so much less as might be thought proportionate considering the different states of young and of mature cane. The causes at work are twofold; when the cane is young the whole ground is exposed to the direct rays of the sun and to the action of winds; when the cane is older the foliage shades the ground and lessens loss due to evaporation, and to a large extent conserves water in the

soil. At twelve months of age the crop actually consumes in its economy ten times as much water as a crop one month old, but owing to the causes mentioned above the apparent consumption is much less disproportionate.

It was found by experiment in Hawaii that the best results were obtained when the young cane received 0·5 inch per week; less favourable results were obtained when the water supplied was one inch per week, and when the furrows were filled with water the cane came up yellow and sickly. As the cane comes away it requires about one inch weekly up to three or four months, after which 1·5 inches are necessary until the crop is in full vigour when three inches and never more are required. These figures refer to natural and artificial supplies combined. The reports quoted above give as a general figure that 1000 pounds of water are required per pound of sugar produced, and mention that certain plantations in Hawaii use much more water than the quantities cited with less favourable results.

TABLE GIVING WATER USED IN PRODUCTION OF A CANE CROP.

Period of Application.	Monthly Rainfall. Inches.		Irrigation Water Monthly. Inches.
July	0·94	..	4·0
August	1·58	..	4·0
September	0·88	..	4·0
October	1·75	..	3·0
November	1·32	..	3·0
December	1·86	·.	2·0
January	1·00	..	4·0
February	3·75	..	1·5
March	3·98	..	3·0
April	0·85	..	4·0
May	2·01	..	4·0
June	0·88	..	7·0
July	0·17	..	7·0
August	1·90	..	9·0
September	0·75	..	8·0
October	2·92	..	6·0
November	0·47	..	3·0
	27·01		76·5

The following figures taken from the same source contain much information regarding irrigation in Hawaii.

Gallons of water used by the crop per acre :—

Crop.	Volume of the rainfall per acre. Gallons.		Volume of the irrigation per acre. Gallons.		Total water received per acre. Gallons.
1897-98	1,260,150	..	1,273,700	..	2,533,850
1898-99	728,990	..	2,059,600	..	2,788,590

Total consumption of water per pound of sugar produced :—

Crop.	Weight of water used per acre. Lbs.		Weight of Sugar produced per acre. Lbs.		Water used per lb. of Sugar. Lbs.
1897-98	25,338,500	..	24,775	.·	1023
1898-99	27,885,900	..	29,059	..	959

The privately owned irrigation works in the Hawaiian Islands are unparalleled in other sugar countries, and are indeed comparable with irrigation works developed in connection with any agricultural undertaking elsewhere. Three methods of obtaining water are to be distinguished :—

1. Pumping from subterranean sources.

2. Interruption of upland sources and conveyance to the plantations by systems of canals, tunnels, syphons and flumes.

3. Collection of upland streams in reservoirs.

The pumps are mostly located at or near sea level as it has been found less expensive to elevate the water through long pipe lines, than to sink shafts

FIG. 19.

at a high level and install regular mining pattern pumps. At the moment of writing (1909) the total water pumped daily to an average height of 200 feet in the Hawaiian islands is estimated at 595,000,000 gallons; the horse power required to effect this service is estimated as 20,000. Of this quantity of water 360,000,000 gallons are pumped in the Pearl Harbour district of the island of Oahu; 150,000,000 in Central Maui and the balance on the island of Kauai.

The second method of obtaining water is developed chiefly on the islands of Maui and Kauai, and latterly has been extended to some districts in Hawaii; altogether the ditches deliver upwards of 600,000,000 gallons daily.

The total capacity of the reservoirs in the Hawaiian islands is over 8,000,000,000 gallons; the largest is that at Wahiawa, on Oahu, holding 2,750,000,000 gallons, and hence of the same capacity as that at Craig Goch, one of the reservoirs supplying Birmingham, England.

O'Shaughnessy[2] estimates that 1,000,000 gallons per day per 100 acres is the duty of water in this district; this is equivalent to 134 acre-inches in a year, not counting natural rainfall and evaporation, which may amount to 50 inches. In a crop period of 18 months, then,

FIG. 20.

22,800 tons of water per acre will produce 50 to 80 tons of cane. He further estimates that owing to leaky ditches, reservoirs and unequal and improper distribution, not more than one-third reaches the area of the cane roots.
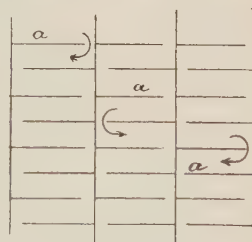
Peru.—In Peru cane is entirely dependent upon irrigation, the melted snow of the Andes being the source of water The arrangement of the ditches generally followed is shown in *Fig. 19*. The *regadora*, or main canal, leads across the higher part of the field; from this, by means of a temporary opening, water is brought to the *cavesera* and is allowed to flow out and run over the

cintas or beds of five rows. The fields are all on the slope, and water is seldom pumped back, but is allowed to flow on the fields at a lower level. Where water is scarce the fields are arranged as in *Fig 20 ; aa* are dividing ridges made with a hoe, and cause the water to run in a zigzag fashion over the field. At planting, fields are irrigated every five to eight days, and after establishment monthly, water being cut off three months before harvest. The water supplied is not abundant, seldom more than equivalent to a rainfall of 20 inches per annum; but copious dews and heavy mists are frequent, and the perfect control of water permits crops being grown with less water than if the canes were supplied with a natural rainfall falling intermittently in varying quantities.

Mauritius.— In Mauritius, in parts where the rainfall is extremely scanty, a few estates are entirely dependent upon irrigation. A sketch of the system usually adopted to water fields is given in *Fig. 21 ; aa* is the main canal, sometimes built of stone, and sometimes formed in the ground; *bb* are channels formed in the fields down which the supply from *aa* is turned; *cc* are the cane rows along which the water is deflected by temporarily damming the channel *bb*. After one strip of the field has been irrigated, say, the one on the right (*Fig. 21*), the water from *aa* is turned into the second channel *bb*, and a second strip watered, and so on.
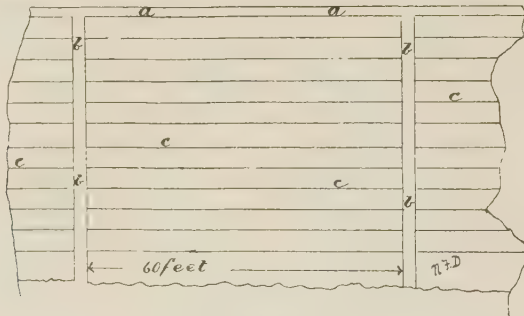
FIG. 21.

The length of the strips in Mauritius is usually about 60 feet, and the water flows only one way. From observations made by the writer an irrigation of young cane took 3·86 inches of water per acre calculated over the whole acreage. This large amount was in great part due to the system of planting in holes; these holes are about six inches deep by four inches wide and nine inches long, and each one has to be filled with water and to overflow before the current can pass on to the next hole along the row. The cost of irrigation is for labour alone about one rupee per acre ; the water used is always obtained by gravitation from higher levels.

West Indies.—The West Indian crops are mainly dependent on rainfall ; latterly, however, in Cuba, Porto Rico, and Jamaica irrigation schemes of no inconsiderable magnitude have been incepted or are in actual operation.

Regnoso estimates that in Cuba the majority of the plantations require every ten days an irrigation equal to 1000 cubic metres per hectare, or 40 tons per acre per day.

Egypt.—In Egypt, according to Ronna[3], the cane is watered as soon as it is placed in the furrow in the month of February; other irrigations follow every ten days until the end of August. From this time up to the end of October every fifteen or twenty days, after which irrigation is stopped. The water required at each irrigation is, according to Tiemann[4], 1000 cubic metres per hectare.

Demerara.—The method by which fields are irrigated will be easily understood on referring to *Figs. 38 and 39*; a drain indicated by the line g is dug parallel to the cross canal c, and connected to it. Down the centre of the beds irrigation drains 15 inches wide and 9 inches deep are dug, along which the water runs into the main drain f and thence to the drainage trench c.

In the 'English' fields, the main drainage trench is dammed at the proper points and the navigation water is cut into the field so that the field or fields can be swamped.

Although the water available in the rivers is beyond realization, irrigation is but little practised and its results are often harmful; the best ever accomplished is the prevention of the entire loss of the crop. To the student of sugar literature, soil and topographical conditions have a great resemblance to those of Java where irrigation succeeds; the only occasions when the writer has seen irrigation tried was in "English" fields when a system of lateral seepage obtains. Harrison[5] has demonstrated the alkaline nature of the subsoil waters of this district and their toxic action; such a system would bring these waters to the surface, and here may lie the cause of the failure. With a system of subsoil drainage the possibilities of irrigation are very great.

Java.—The irrigation works in Java are of great magnitude, and are entirely under state control. Conditions here are entirely different from those in Hawaii, due to the enormous native population (over 30,000,000) whose interests in the water available (used by them mainly in the rice crop) are zealously guarded by the Dutch Government, which apportions the amount of water to be used by the European cane planters and by the native peasants.

Geerligs[6] has given the following details of cane irrigation in Java:—

"In consequence of the intensive cultivation of the cane in Java the soil is quite dried to a considerable depth and absorbs an enormous quantity of water. This can be estimated at two or three hectolitres per bouw* per second (equal to $3\frac{1}{2}$ to $5\frac{1}{4}$ cusecs per acre) at planting; if at the age of two or three months the soil is gradually saturated, in the absence of rain, only sufficient

---

*A bouw does not seem to be a very definite area; in one authority I find it put equal to a hectare or 10,000 square metres; in another to 500 Rhynland roods or to 1·67 acre. In a paper by Kanmerling dealing with the water transpired by the cane a bouw is taken as 8000 square metres, *i.e.* 1·97 acre. According to Geerligs, 1 bouw equals 500 square Rhynland roods or 1·75 acres. I have translated the quantities in this section into cusecs per acre, taking the bouw as two acres, and the hectolitre as 3·525 cubic feet.—(*N. D.*)

water is applied to make up the losses from evaporation. This loss is, from experiments upon the transpiration of the sugar cane, about ·006 to ·009 cusecs per acre. Generally a flow of ·0176 cusecs per acre is sufficient for the cane, but the majority of irrigation works do not afford more than half this quantity.

"The nature of the soils determines the necessity for irrigations after the rainy season has stopped : some soils contain so much water that irrigation is quite unnecessary, the roots of cane aged 10 to 12 months being quite satisfied with the natural humidity of the soil. In the case of sandy soils where drainage is easy, or in very stiff clays where the deep growth of the roots is prevented, so that the root system is contained in the upper layers, it is some-times necessary to introduce a little water into the ditches to prevent the drying up of the roots."

A point of great interest in regard to irrigation water in Java is the great manurial value of the silt carried in the water. According to de Meijier[7] the Solo river carries on an average 1 kilo of silt per cubic foot ; the silt of the Brantas canal water contains from ·43 to ·60 per cent. potash, from ·35 to ·65 per cent. phosphoric acid and ·25 to ·27 per cent. nitrogen. It is this large quantity of mineral matter in a finely divided state that saves sugar cane planters in Java from the purchase of mineral manures.

Formosa. —At the time of writing, very extensive irrigation schemes, under the control of the Japanese Government, are being pushed forward.

Economic Distribution of Water.—So far as the somewhat scanty information available on cane irrigation in Java allows an opinion to be formed, it seems that the irrigation serves as a means of saving the cane during the dry season and not, as is often the case in Hawaii, of obtaining the maximum possible crop. It has been established that cane 15 months or so old consumes and requires for its maximum growth the largest amount of water, and in Hawaii such cane often receives as much water as it can utilize. In Java, however, there does not seem to be a sufficiency for both young and old cane ; in this case it is the former that receives the water as the older cane can still remain in fair vegetative vigour on the supplies of soil water, where the younger cane would fail to become established.

In Hawaii it not infrequently occurs that the supply of water is insufficient to afford the optimum quantity to all the cultivation ; here there is a balance of opinion in favour of stinting the young cane and giving the full amount to the old cane. Mauritius experience favours the irrigation of young cane to the detriment of the older.

Hence we have here a question of very great importance concerning which no experiments seem to be on record, and which would be very hard to plan satisfactorily.

Water transpired by Cane.—Maxwell[1] found as the result of experiment that when cane was grown in tubs, in seven months 79,310 grms., or 174·5 lbs. of water were transpired by the plant, there being formed 568·9

FIG. 14.
STRIPED
TANNA.

2
3
SIZE

PLATE VI

grms. of water-free material, consisting of 31·8 grams roots, 53·9 grms. stems, and 483·2 grms. leaves, or 147·8 lbs. water per pound of water-free plant material. The amount of water transpired in each month of growth was found to be as in the annexed table.

Time of Observation.	Age of Cane. Months.	Transpiration. Grms.	Time of Observation.	Age of Cane. Months.	Transpiration. Grms.
May	1	.. 860	August ..	4	.. 19,800
June	2	.. 6500	September..	5	.. 20,050
July	3	.. 11,000	October ..	6	.. 21,100

Experiments due to Kammerling[8] in Java showed that on an average one stick of cane by its leaves transpired over its whole period of growth 250 c.c. per day; this he estimates as equal to 3,500,000 litres per bouw over the whole vegetative period, or equal to about 1800 tons per acre.

During the first month of drought in Java, Kammerling estimates the transpiration per stick as 500 c.c. per day, and using this as a basis he reckons that the replacing of the soil water thus transpired in a month requires 720,000 litres per bouw, or about 370 tons per acre.

Kammerling also observed that the transpiration of the Manila, Cheribon and Muntok canes was as 5 : 4 : 3 ; *i.e.*, the latter will remain in vegetative vigour on the soil water longer than the former, and will be drought resisting.

Methods of Irrigation.—Hilgard[9] distinguishes the following methods:—

1. Surface sprinkling.
2. Flooding.
    (*a.*) By lateral overflow from furrows and ditches.
    (*b.*) By the check system.
3. Furrow irrigation.
4. Lateral seepage from ditches.
5. Basin irrigation.
6. Irrigation from underground pipes.

The first method can be seen in practice in Demerara, where in seasons of drought the 'creole gang' (the colony-born children of the imported Asiatic labourer) are employed laboriously carrying water in buckets to the 'stumps' or stools of canes transported from an abandoned field to fill blanks in one still under cultivation; this method can only be used where labour is of the cheapest.

The second method is extravagant in the use of water, and is illustrated in the methods described below as in use in Peru.

The fourth method is exemplified in the so called flooding of the 'English' fields in Demerara mentioned above.

The fifth and sixth methods do not find application in cane planting.

The third method is the most rational method, and the one which is most largely applied. The system advocated by Maxwell[1] is shown in *Fig. 22.* Water from the main water ditch *AA* is diverted into the laterals *bb*, andfrom these laterals allowed to flow in two directions along the furrow in which the cane has been planted; this twin flow of water may be compared with the diagram in *Fig. 21*, illustrative of the practice in Mauritius. In *Fig. 22* the laterals are only thirty feet apart, so that the water only flows fifteen feet; a longer flow results in those portions of the cane row near the lateral receiving an excess of water, and those more remote not receiving enough. In case the flow of water is scanty or the soil is very porous, such a system is necessary so as to allow water to reach all parts of the field; but it would often be
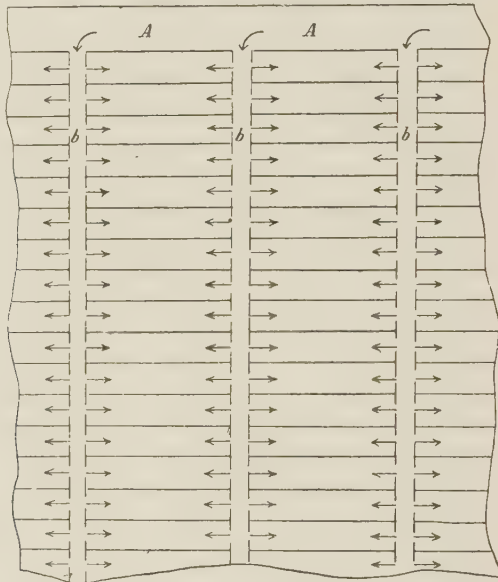
Fig. 22.

hard to lay out. As illustrative of a wasteful and harmful method of irrigation, Maxwell gives the following diagram (*Fig. 23*), where the water from the main ditch *AA* flows along the cane rows for the whole length of the field exaggerating the waste and damage due to long furrows.

The length of the furrow is very largely controlled by the porosity of the soil; with light, sandy, porous soils, a short furrow is necessary to prevent undue waste of water; and where the soil is clayey, so that the water penetrates more slowly, a longer furrow is allowable.

Quality of Irrigation Water.—Maxwell[1] arbitrarily fixed the 'danger point' of irrigation water at 100 grains of salt per imperial gallon; Hilgard[10] states that 40 grains is the usual limit. Eckart[11] found cane in lysimeters grew unchecked when the soil water contained 195 grains chlorine, as sodium chloride, per U.S. gallon and obtained in lysimeters a normal growth

when irrigation water containing 200 grains of salt per gallon was used in excess, thus permitting good drainage from the porous soil employed in the tests. He also found that gypsum and coral sand mitigated the harmful effect of saline irrigation waters.[12]

The nature of the salt in the water has a profound effect ; sulphates or carbonates of lime and magnesia are not harmful ; it is in the chlorides of the alkalies that danger lies. The danger of such water lies in their abuse rather than in their use ; if the soils to which they are applied are ill-drained so that the salt can accumulate, the quantity soon becomes toxic ; the natural rainfall, applications of a purer supply or heavy applications of the saline water, combined with good drainage, so as to wash out the accumulated salt, permits their safe use.
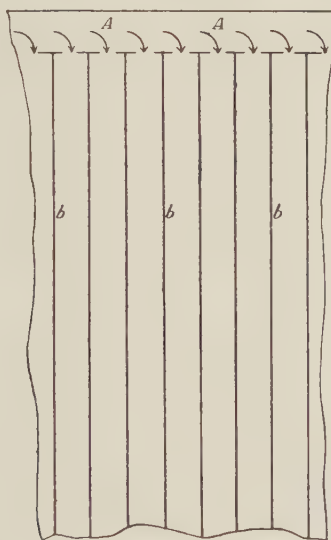
FIG. 23.

Conservation of Soil Water.—After the water has arrived in the soil a great part is always lost by evaporation, and this is capable of control within certain limits. A protective layer of soil in fine tilth prevents the upward movement of the water by capillary attraction to the surface, and is highly efficient in retaining water in the soil. Not less important is the nature of soil ; soils containing much humus are especially water retentive, and this is capable of control in the burying of the trash of the cane and in the plowing in of green manure ; to a certain extent the benefits of these practices may be attributed to the increased water holding capacity of soils treated in this way.

The velocity and flow of the wind are also of importance in determining the evaporation from the soil, and loss in this way may be controlled by planting wind breaks or belts of trees.

Another factor of very great importance is the humidity ; Eckart[11] has shown that this entirely masks the effect of temperature, so much so that a

rise in humidity of 12·5 per cent. decreased the evaporation 50 per cent., although the temperature rose 1·5° Fahrenheit.

Cessation of Irrigation.—In Hawaii it is customary to stop the supply of water when the cane has flowered. Such cane is usually harvested from three to six months after flowering, and during this time little or no growth takes place, the cane actually evaporating its own water; and at the same time it probably elaborates reducing sugars into cane sugar. Such cane may receive during the time of ripening a small amount of water to maintain its vitality.

Optimum Quantity of Water.—Experiments by Eckart[13] showed that under the conditions prevailing at the Experiment Station of the Hawaiian Sugar Planters' Association, the maximum return of cane was obtained with a three-inch weekly irrigation. Commenting on these results, he writes:—" These experiments have a practical bearing on irrigation on plantations, as they show that while the larger volumes of water gave an increased production of sugar, such increase of sugar would, under some conditions be obtained at a loss. For instance, if we were to take the average cost of lifting 1,000,000 gallons of water one foot to be $0·09, where three inches per week irrigation were applied it would cost $42·77 per acre at the 100 feet level. One inch of water at the same elevation would cost $14·90. The additional cost of irrigation in increasing the yield of sugar 2081 lbs. would be 2·6 cents or 1·3 cents per pound. At 200 feet elevation, the cost per pound of sugar gained by increased irrigation would be 2·6 cents, and at 300 feet elevation, 3·9 cents. Naturally, these calculations are for a soil similar to that at the Experiment Station and receiving about the same rainfall."

Optimum Percentage of Water in Soil.—Eckart[13] found that when three inches of water was applied per week, the soil at the Experiment Station in Honolulu contained on an average 31·38 per cent. of water; this soil can according to him absorb 40·74 per cent. of water *in situ;* hence he finds that the best results are obtained when the soil is saturated to 77 per cent. of the maximum. This is a larger figure than is found with most other crops.

Cost of Irrigation.—The total capital expended in the Hawaiian Islands on sugar cane irrigation is probably not less than £3,000,000; but statistics are incomplete and this is certainly a very conservative estimate. Amongst figures that have been published, may be quoted those referring to Ewa, where the total cost of erection of pumps delivering 22,000,000 gallons daily was £370,000 ($1,775,000). The Olokele ditch 13 miles long, through a mountainous country and delivering 60,000,000 gallons daily, cost £75,000; the cost of the Kekaha canal on Kauai, of the same length and capacity, was a similar figure. The Koolau ditch built through very difficult country and ten miles long cost £91,000; it delivers 80,000,000 gallons daily. The Kohala ditch on Hawaii which is 14 miles long, 12 feet wide at top, 7½ feet wide at

bottom, and $4\frac{1}{2}$ feet deep cost £83,000; this ditch is a private undertaking and sells water to a number of plantations, the price charged being $2500 per year per 1,000,000 gallons per day.

Stubbs[11] quotes the cost of irrigation at Ewa as being $73·75 per acre per year, of which $36·62 were for pumping and $37·13 were for labour. Another estimate gives the cost of pumping with coal at $8·10 per ton, and expressed per 1,000,000 gallons lifted one foot as—

	$
Operating expenses	·081
Interest 6 per cent.	·014
Depreciation	·007
	·102

With oil fuel the total expenses are reduced to $·074 for the same quantity.

This cost of irrigation may appear prohibitive until it is remembered that in the Hawaiian Islands the average return per acre on unirrigated plantations is, year in year out, about three tons of sugar per acre, and on the irrigated plantations about six tons, so that three tons of sugar, less cost of cutting, hauling and manufacture, are to be credited against $73·75 as the cost of irrigation.

Some recent information regarding cost of irrigation in Porto Rico[15] gives not dissimilar figures; it is stated that here $25 per acre is the lowest figure for pumping expenses, and that it often reaches $50. An estimate of the Patillas and Carite schemes in this island, designed to irrigate 13,000 acres, gives the total cost as $1,215,000, or nearly $100 per acre.

REFERENCES IN CHAPTER VII.

1. *U. S. D. A. Office of Exp. Stations, Bull.* 90.
2. *Trans. Am. Soc. Civ. Eng.* **54,** 129.
3. *Les irrigations.*
4. *I. S. J.,* 50.
5. *W. I. B.,* **9,** 1-36.
6. *Bull. Assoc.,* **19,** 1412.
7. *Trans. Am. Soc. Civ. Eng.,* **54,** 40.
8. *Proceedings 4th Congress of the United Syndicate of Java Sugar Manufacturers* (1900).
9. *Soils,* p. 234.
10. *Soils,* p. 248.
11. *H. S. P. A. Agric. Bull.* 8.
12. *H. S. P. A. Agric. Bull.* 11.
13. *H. S. P. A. Agric. Bull.* 9.
14. *U. S. D. A. Office of Exp. Stations, Bull.* 95.
15. Willet & Gray's *Weekly Report,* 11, 11, 09.

CHAPTER VIII.

THE HUSBANDRY OF THE CANE.

The cane is grown under so many diverse conditions that no general sketch of its husbandry is possible. An attempt is made in this chapter to give some short notice of the implements employed and the routine of operation in the more important districts. Broadly speaking, the districts where the cane forms a staple fall into two classes; those where the cultivation is chiefly manual and those where animal or power operated implements are used. The former methods are chiefly employed in the presence of a cheap supply of labour of Asiatic or African origin, but the physical conditions of the district have also a large influence.

FIG. 24.   FIG. 25.

Manual Implements.—The manual implements used in the cultivation of the cane are the hoe, the fork, the shovel and the cutlass. The cutlass, two forms of which are shown in *Fig. 24,* is used in the British West Indies as a weeding tool. In other districts this work is done with the hoe, two forms of which are shown in *Fig. 25;* the short handled hoe is used in Mauritius, and the long handled form in Demerara; besides being used to cut down weeds, it is employed to hoe earth over the rows of cane and to make the cane furrow; in Mauritius this tool is also employed in making the holes in which the cane is planted. The fork, *Fig. 26,* is employed in Demerara in the

cultivation of the cane when *forking banks*, *i.e.*, turning over with the fork the soil between the rows of cane. The shovel, *Fig. 27*, is used in Demerara in preparing the seed bed, and in digging drains.

Animal and Power Implements.—With few exceptions the same implements that are employed in the husbandry of other plants find use with the cane; these include steam, gang ploughs, turn or mould-board, shovel and disc ploughs, harrows, tongue and disc cultivators. In this connection it is of interest to note that so long ago as 1848 Wray in the *Practical Sugar Planter* advocated the use of steam ploughs and of cultivators; he illustrated a turn plough operated by one engine on the cable and anchor system; the horse hoes and cultivators that he showed (and the use of which he strongly advocated) differ but in detail from those in use at the present time. His remarks on the use of these instruments are as true to-day as they were two generations back, and are therefore quoted below :—

" The hoe plough is the next instrument particularly deserving of attention ; it is one of the most useful that the planter can employ. This plough is used for the purpose of hoeing up weeds and loosening the earth between the growing plants. It is provided with two wheels, one in front of, and one behind the hoes, by means of which the depth of the hoeing is regulated. It may be used with three

FIG. 27.

triangular hoes, each cutting 13½ inches wide, extending over 3 feet 6 inches of ground, or contracted to a smaller width ; or the two hind hoes may be replaced by two curved knives for cutting the weeds up on the sides of the ridges. It is an implement of very simple construction and in great use in England ; it is also one that will be found of very great advantage on sugar estates, in cleaning between the cane rows, and in loosening the soil about the plants. The expanding horse hoe is an implement designed and manufactured expressly for the colonies, and is already beginning to establish for itself a very sure reputation amongst sugar planters. By means of a very simple contrivance, it can be extended and con-tracted at pleasure ; so that the planter can have it made to expand even to 5½ or 6 feet, if he requires it, as he will in all cases where he plants his canes at six feet apart ; whilst at the same time, by having spare tines or shares of peculiar form, he can vary the nature of the work to be performed by it. For

FIG. 26.

instance, the instrument is suited for rooting up weeds and loosening the soil between the rows of canes ; by taking off the tines and hoes and replacing them with light moulding shares, the instrument is at once converted into a moulding machine, whereby the young canes may receive two or three successive mouldings as lightly and neatly as by hand labour.

"I consider this machine to be so valuable to the planter, that no sugar estate should be unprovided with it; it enables him to perform at a very inconsiderable cost an amount of work which, when executed by hand labour, is well known to be very tiresome and expensive."
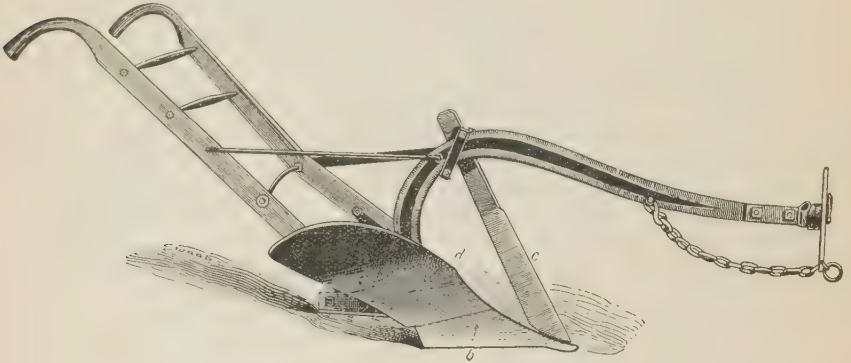
FIG. 28.

Turn or Mould-Board Ploughs.—Turn or mould board ploughs are so called because they cut from the soil a clean slice and turn it over top side down, through the action of the mould board; the single mould board plough is shown in *Fig. 28; a* is the share, *b* the landslide, *c* the coulter, and *d* the mould board. The coulter shown is of the knife type; it may be replaced by a rolling coulter, consisting of a revolving steel disc, and instead of being hung from the beam, it may be bolted on to the share or may be entirely absent. This type of plough is the instrument that is almost always used in
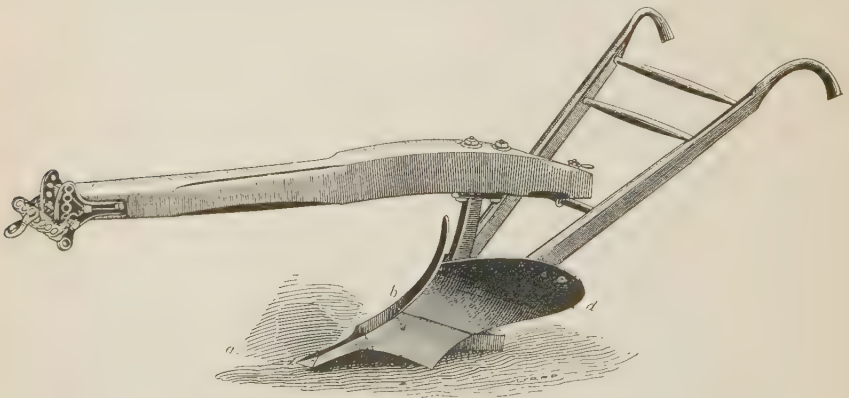
FIG. 29.

the preparation of land for planting crops of all kinds; the plough may be a single unit, or there may be a number of units forming a *gang plough*. The double mould board plough is shown in *Fig. 29*, the lettering being as for the

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PLATE VII.

Fig. 31.

single mould board plough. This plough throws a slice of earth on either side of the share, and finds an extended use in the sugar industry in forming the furrows in which the cane is planted, in opening irrigation channels, in 'bursting out' the middle of the cane rows, and in turning over weeds between the rows in young canes.

Disc Ploughs.—The essential part of the disc plough (*Fig. 30*) is the revolving discs; these are of concave shape and revolve about their centre; the slice of soil is turned over by the action of the concavity of the disc.

The disc principle was originally devised to lessen the draft on the plough and these ploughs find use in tenacious soils, where the mould board plough will not scour properly, and in very hard lands where it is not possible to use the latter plough. In open loose soils the disc ploughs are inferior to the other type.
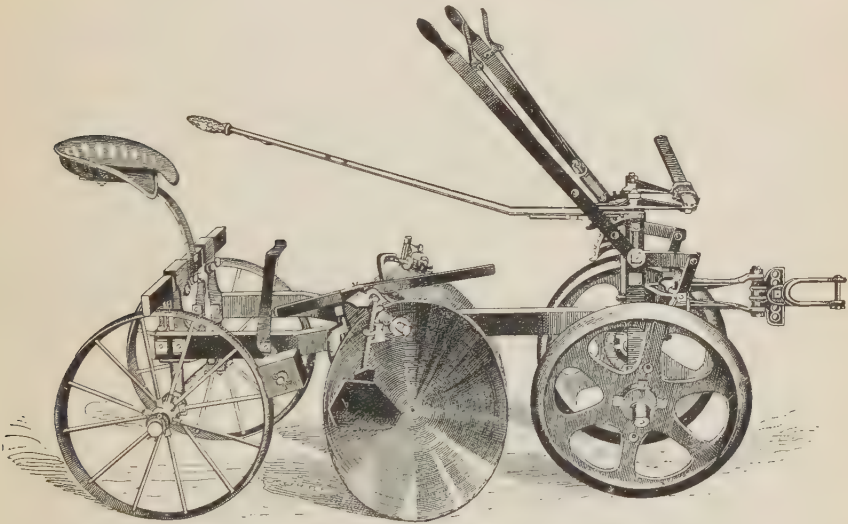
Fig. 30.

By the use of two discs inclined towards each other, they may be used for furrowing, and they also find one of their most extended uses in turning over and burying the pea vines grown as a green manure.

Steam Ploughs.—This term applies only to the power by which the plough is operated, the latter remaining essentially the same in principle as already described; instead, however, of there being only one plough, a number are combined into one implement, the whole forming a *gang;* as many as seven may be united in one gang, the ploughs being either mould board or discs. Two methods of applying power may be distinguished; in one the plough is hitched directly to the engine which draws the plough across the field. In the other two engines are required; these are located on opposite sides of the field; each engine is furnished with a winding drum, and through the agency

of a wire cable draws the plough to and fro across the field, each engine working alternately; the plough is equipped with a double set of plough shares on opposite sides, so that one set is tilted in the air when the other is buried in the ground. This type, which is shown in *Fig. 31* (PLATE VII.), is used extensively in the Hawaiian Islands.

The Cultivator.—A form of cultivator which has developed from the shovel plough or horse hoe is shown in *Fig. 32;* this instrument, in cane growing, is drawn by animal power between the rows of cane, breaking up the soil and at the same time destroying the weeds.

Disc Cultivator.—The disc principle has also been applied to cultivators, a form of which is shown in *Fig. 33;* this instrument is arranged to *straddle* the row, the discs being set so as to throw dirt on to the row. Such an implement finds its most extended use in Louisiana.
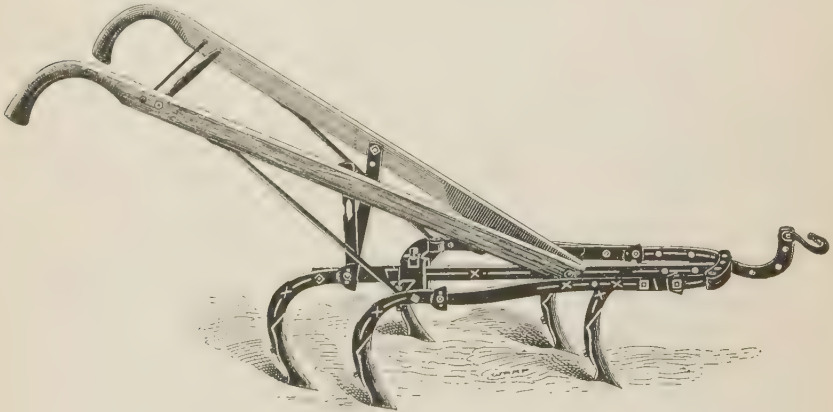
FIG. 32.

Cultivators can only be used in young cane, and when the crop is so far grown as to prevent their use it is said to be *laid by*.

Harrows.—The harrow was devised as a means of lightly covering seed laid down after ploughing with turn ploughs; in cane cultivation it is used after ploughing to reduce the soil to a fine tilth, to break up clods and to level inequalities. Its use may be supplemented by the employment of rollers. The disc principle has also been extended to harrows.

Special Cane Implements.—In *Figs. 34, 35,* and *36* are shown the Benicia-Horner No. 1. Ratoon and Cane Disc Plough, which has found an extended use in the Hawaiian Islands; it contains in detachable parts a double mould-board plough, a revolving knife, right and left hand discs, and a subsoil plough; it may be used as a furrower either for planting or for irrigation, for bursting out middles, as a cultivator for throwing soil on to the cane row or with the object of hilling up the latter, for trimming and subsoiling the sides of the cane row, and slicing and cutting the ratoon row.

When used as a furrower for planting or irrigation the implement is equipped with both right and left hand discs, with the double mould plough and with the subsoiler; when used to slice up ratoon cane the plough is replaced by a revolving knife; when used for hilling up rows of cane the revolving knives and discs alone are used, the subsoiler being detached.

In *Fig. 37* is shown the Horner combined weeder, cultivator and harrow, intended to be used where the growth of grass is very rank; it was originally designed to be used with the *Hona hona* grass of the Hawaiian Islands; the semi-circular teeth tear up the weeds and at the same time cultivate the soil. The load of weeds gathered in the cradle can be discharged by lifting up the handles of the implement.
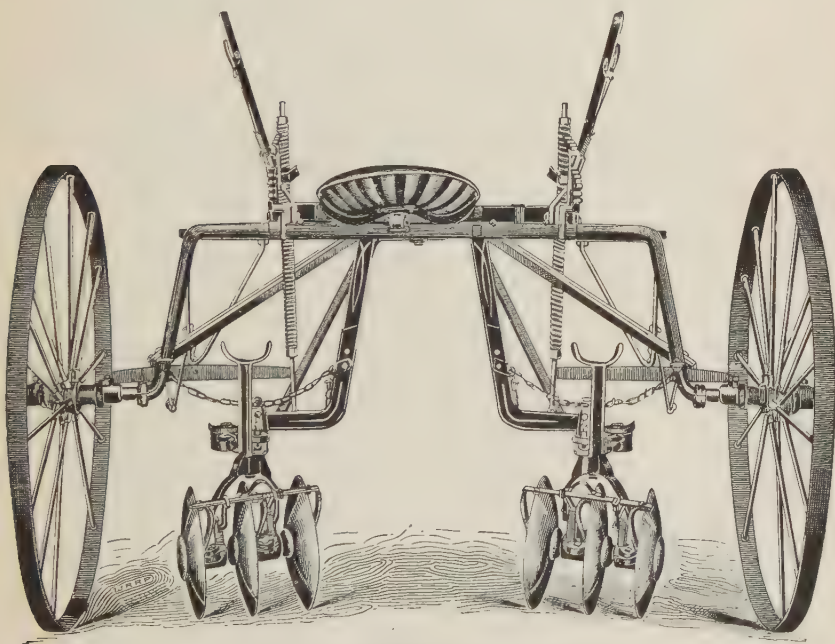
FIG. 33.

Other special cane implements are the *Stubble shaver* and *Stubble digger* in use in Louisiana. The former is a horizontal rotatory knife revolving when the carriage, of which it forms a part, is drawn along; it is used to cut down stumps flush with the ground. The essential part of the *Stubble digger* is a shaft on which are fitted blades arranged along a helix. When the carriage is drawn along the rows of ratoon cane the knives revolve and break up and pulverize the soil.

Preparation of the Land.—Although the greater part of the cane sugar yearly produced is manufactured from cane grown on land that has now been in cultivation for a number of years, and in many sugar producing countries all available land is under cultivation, in some other countries virgin

land is still taken in, or old abandoned land that has fallowed for a number of years and returned to its primitive condition is again put under cultivation. In general the operations to be undertaken in putting in new land may be briefly described as under :—The land is cleared of all trees and bush, the heavy wood is put on one side to be used as fuel, or, if valuable, for export, the small branches, leaves, and bushes being burnt *in situ*. Very generally all this work is done by hand and the cost, especially if heavy stones (as is often the case in volcanic countries) have to be moved, is very great. The more modern and economical method is to employ steam power; engines capable of use either as traction or stationary engines are employed in many countries
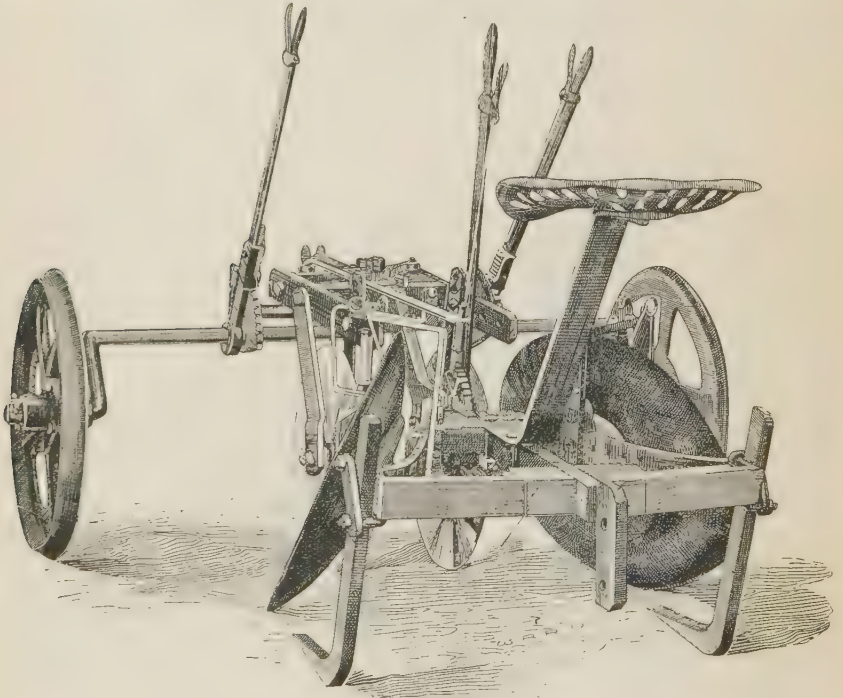
Fig. 34.

for the purpose of hauling the heavy timber and large stones off the land ; when new districts are opened up or when new land is continually taken in such a process is almost essential.

The combustion of the vegetation on new land is from one point of view entirely wrong, for the practice robs the soil of most of the nitrogen that has been accumulating for ages past; but the expense of burying the vegetable matter, the slowness of its decomposition, and the harbouring places it affords for noxious insects are the reasons for maintaining this universal practice ; in addition, the burning of the vegetable matter places in the soil a large amount of readily available mineral plant food.

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After the land has been cleared in those countries which employ land carriage, roads wide enough for carts to pass are made through the new sections, and the area divided up into convenient fields; the land is prepared for cultivation by ploughing, either by manual, animal, or steam power.
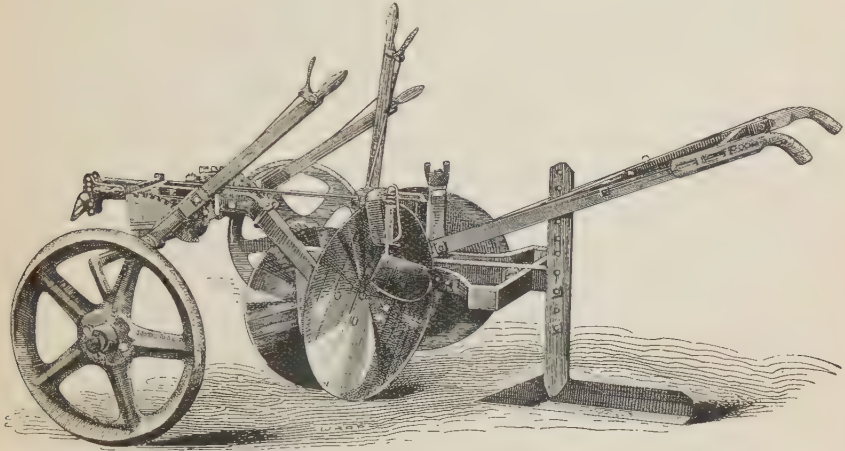
Fig. 35.

When hand labour is employed, the soil is merely turned over by forks or shovels; in other cases the whole area is ploughed, cross-ploughed and horse-hoed, and the soil properly broken up and aërated.

British Guiana.—In British Guiana and the Straits Settlements, which are flat alluvial countries, a somewhat more complicated procedure is
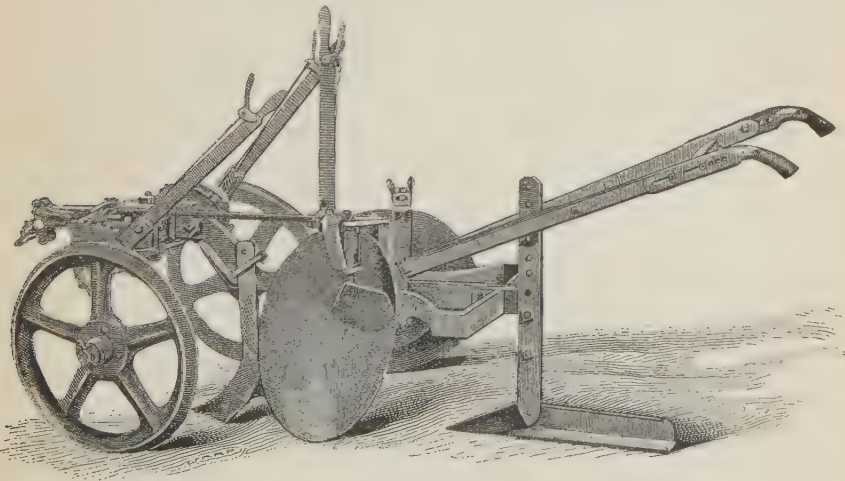
Fig. 36.

necessary; the area of the new plantation being decided, three dams formed by the excavation of three trenches are thrown up. These dams are known as the navigation or middle walk, sideline or drainage, and back dams, and they

enclose the piece of land which is to be put into cultivation; more frequently, however, a double section is formed with two sideline dams and a back dam as empoldering dams, a navigation dam running in the centre of the two half sections, and serving equally for both. In *Figs. 38* and *39* are given plans of the arrangements of field customary in British Guiana; *a* is the navigation dam formed by the excavation of the navigation trench *b*; the navigation trench continues up to the factory, and is used for the transport of cane and produce, and also to supply water for irrigation and other purposes. This canal is connected with a river, creek or lake; or where this is impossible, a large canal capable of supplying a batch of estates carries water from a river. Many estates have pumping stations situated on a river, so that they are nearly independent of drought; on other estates a drought may cause the level of
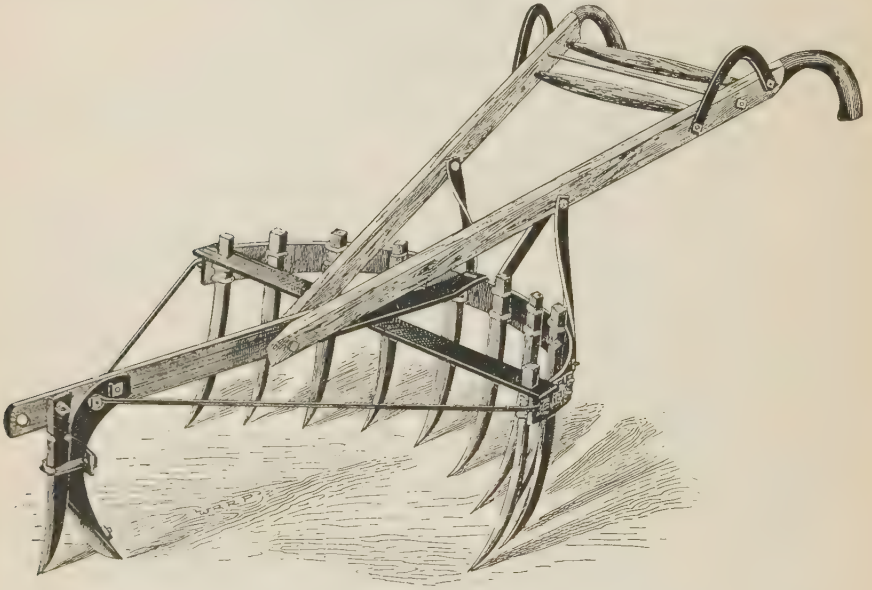
Fig. 37.

water in the river or creek to fall so much that it is necessary to take sea water into the trenches. At *e* are shown cross canals communicating with the navigation trench, and terminating about 20 to 25 feet from the sideline or drainage canal *c*; the cross canals are used for the purpose of bringing the punts or barges used for transport within access of the canes; the main drainage canal runs out to the sea or river. Drainage is either forced or natural; in the former case centrifugal or sluice wheel pumps are employed, the first named being by far the most economical; in the latter case the side-line discharges at low tide into the sea or river. Between the cross canals lie the fields, usually of area 10 to 20 acres, the distance from cross canal to cross canal being about 500 feet. In Demerara two kinds of fields are
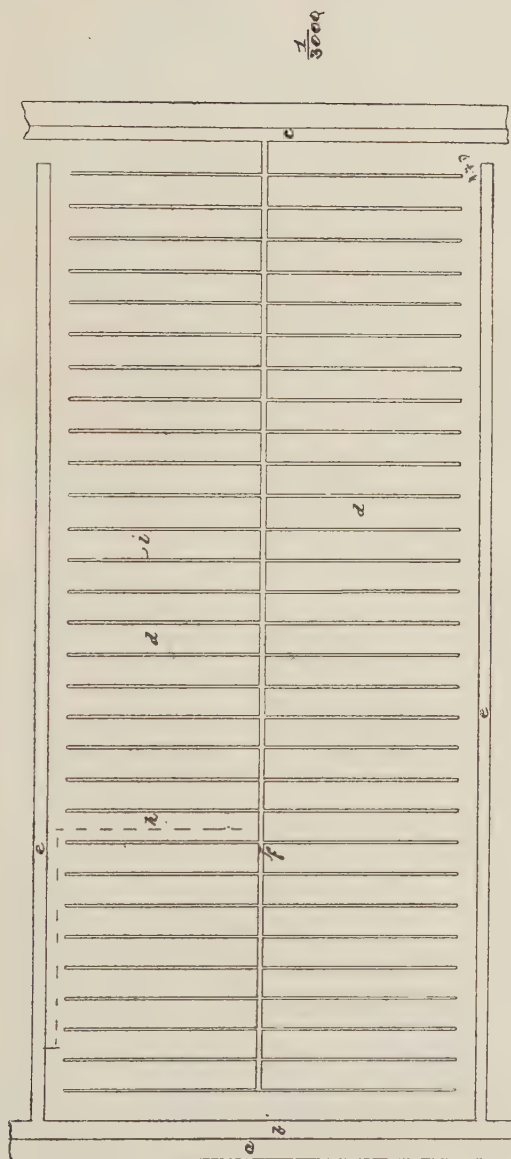
Fig. 38.

distinguished : Dutch fields, *Fig. 38*, and English fields, *Fig. 39*. In the Dutch form the fields are divided into beds 35 feet wide, running parallel to the navigation trench ; running down the centre of each field is the drain *f* known as a *tracker* or *four-foot*, which communicates with the main drainage trench ; between each bed are small drains *i* which discharge into the four-foot. In the English fields the beds *d* run at right angles to the navigation trench. There is usually one bed *g* called the dam bed, running parallel. In front of the dam bed is a cross tracker *h*, and between the beds are the small drains *i*. Through the centre of the field runs, as before, the four-foot *f*. The drains *i* discharge both into the cross tracker, and thence by *f* into the main drainage trench, and also directly into the main drainage trench ; very often a centre cross tracker is also provided. The dam, called the back dam, is not shown in the sketches. It is the last dam on the estate, and serves to keep out Savannah water.

Approximate dimensions customary in Demerara are : Navigation trench : 16 feet-20 feet top ; 12 feet-16 feet bottom ; 4 feet-5 feet deep. Cross canals : 12 feet top ; 9 feet bottom ; 4 feet-5 feet deep. Small drains : 2 feet-3 feet top ; 1½ feet-2 feet bottom ; 3 feet deep. Larger drains (trackers) : 5 feet top ; 3 feet bottom ; 4 feet deep.

No furrow is formed in the soil, but a seed bed three to four feet wide is made with the shovel into which the seed cane is pushed in a sloping direction. Between the cane rows is a space about four feet wide called the *bank ;* often on very stiff clayey soils a shallow drain known as a *drill*, running parallel with the cane row, is made in this bank.

Louisiana.— In Louisiana, where the sugar lands are flat and alluvial, little, if any, new land is now taken in for sugar-raising purposes ; the preparation of the old land is as follows. The soil generally bears a plant and ratoon crop of cane followed by corn ; at the last cultivation of the corn the land is sown with cow peas at the rate of from one to three bushels per acre ; an immense mass of vegetation is produced which is ploughed in with disc ploughs as a green manure. When the vines have rotted sufficiently the ridges on which the cane is to be planted are formed with the turn plough ; drains are made at right angles to the ridges ; these quarter drains lead into larger ditches, and these latter into the main drainage canals.

Cuba.— In Cuba, before the era of United States influence, forest land very imperfectly cleared was used for cane planting ; in such land stones and the roots of trees were left *in situ* and no ploughing was attempted ; the land was of such fertility that up to twenty successive crops of cane could be obtained from one planting. When the land became unproductive it was allowed to lie fallow for long periods, and afterwards was again brought into bearing ; by this time the stumps and roots of trees would have rotted, permitting the use of

Fig. 39.

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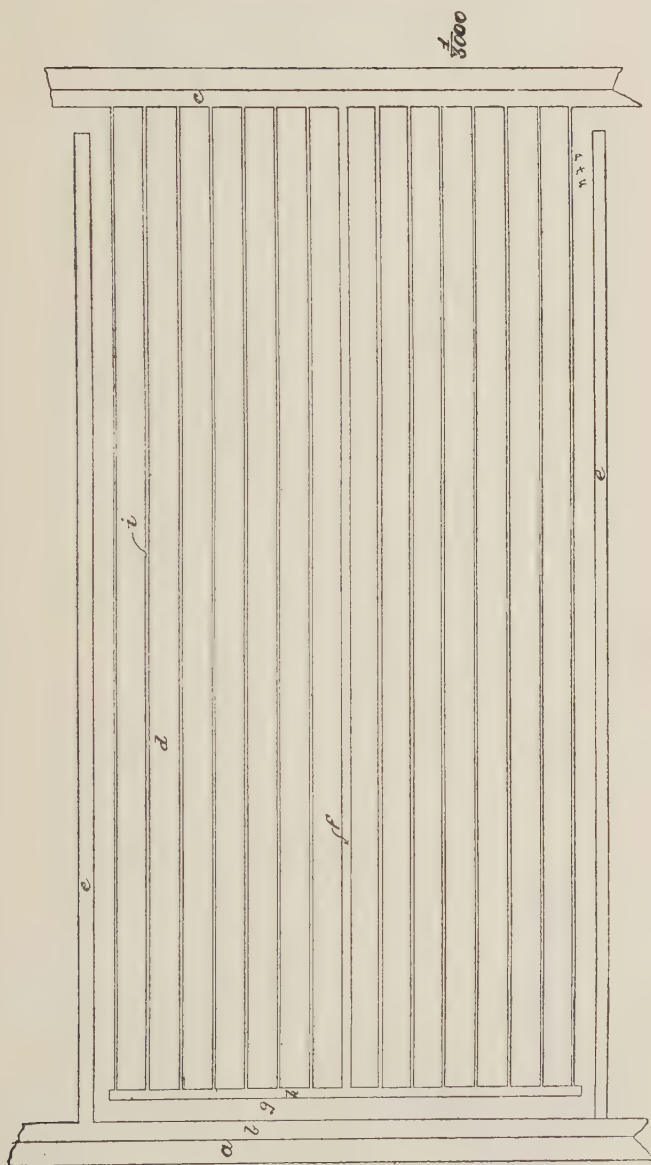
the plough; such land was ploughed with the turn plough drawn by oxen, and furrows made by the double mould-board plough. Of late years more rational methods have been adopted, and the steam plough is now in use.

Hawaii.—Deep and thorough ploughing and good preparation of the soil is a characteristic of this district. A typical routine is as follows : — After the land has carried its last ratoon crop, a plough is run down the middle of the row bursting out and shattering the ratoon rootstocks; the land is then harrowed, ploughed and, perhaps, cross-ploughed. Where the contour of the land permits steam ploughs, generally Fowler cable-operated balanced ploughs, as shown in *Fig. 31*, are used; after ploughing a second harrowing is done, following on which the furrows, and water courses on irrigated plantations, are made with a double mould-board plough. Fertilizer may then be scattered on the bottom of the furrow and mixed with a subsoil tyne cultivator; usually the application of fertilizer is delayed until after planting.

Mauritius.—For very many years past no new land has been available for cane growing; an essential feature of the system of cane growing there followed is the well-advised green manuring given the land after the last (generally third) ratoon crop has been taken off. After the land has been for a variable period under the green crop, this is cut down and buried or burnt off; after lining off the field the holes in which the cane is planted are made with the hoe. The entire preparation of the land is done with very cheap manual labour of East Indian origin.

Java.—The imperative needs of the large native population of Java demand a carefully regulated system of land tenure, and the self-contained plantations found elsewhere are absent from Java. Cane is only planted one year in every three, the land at other times being in the hands of native cultivators; cane generally follows rice, and a number of small separated areas of rice is united into one cane field, the area of which is from one bouw (1·97 acre) to 100 bouws with an average of from ten to twenty bouws.

The first operation is to level the small embankments that have been made in the rice fields, and to separate the terraces and fields belonging to different owners; the rest of the operations are thus described by Prinsen Geerligs[1] :—

"As soon as the rice is reaped, and sometimes during that operation, a deep ditch is dug round the field in order to drain off superfluous water. Owing to the wet rice cultivation the soil has been saturated with water during the last two or three months, all kinds of reduction processes have taken place and oxygen fails entirely. In order then to render the land fit for cultivation the soil must be exposed to the action of sun and wind. To this end the field is divided by transverse ditches into plots of one-quarter or one-fifth of an acre, and between these ditches the rows in which the cane is to be planted afterwards are dug. Ordinarily these rows are 30 feet long, 1 foot wide, a little over 1 foot deep, and 4 or 5 feet apart. The excavated soil is heaped up between the rows. In some places where the nature of the soil so allows, the land is ploughed first and afterwards the rows are dug with the native spade. When the field is thus prepared it has the aspect of a large number of trenches which remain exposed to the sun's rays for about six weeks. It is still unknown what chemical action takes place during the drying of

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the soil but experience has taught us that this period of lying fallow is indispensable in obtaining a good crop. The wet lumps of soil dry up during this operation, crumble to pieces and assume a lighter colour causing the mass of moist cold hard lumps to change into a loose greyish powdery soil. During the weathering all grass is carefully weeded out, and this is continued after planting until the cane has grown so high that it keeps down the weeds by its own shadow. At the end of the drying time the soil in the rows is loosened a little and the cane tops are then planted in them."

A ground plan of a Java cane field will then appear as in *Fig. 40;* at *d* is a ditch surrounding the field into which drain the cross ditches, which are in turn fed by the small drains *c* separating the cane beds *e*; the cane rows are at *b* running across the beds.
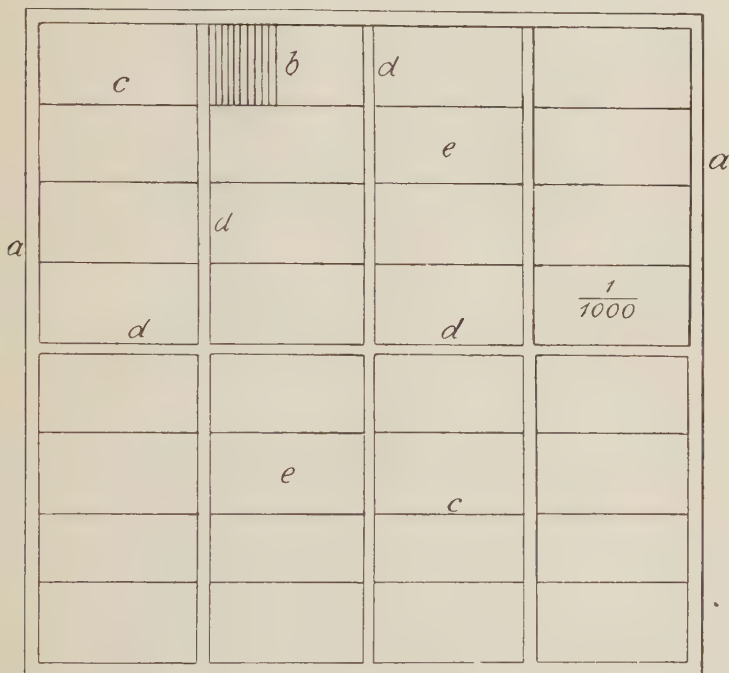
Fɪɢ. 40.

GENERAL AGRICULTURAL PROCESSES.—The agricultural processes followed in connection with cane growing are discussed below; in general similar practices prevail in most districts; differences are determined by the use or absence of irrigation, and of mechanical cultivation, by labour supply, and by purely local conditions.

Planting.—The seed cane is planted in rows or in squares, in furrows or in holes. In furrow planting, which is most generally used, the furrow may be made by the double mould-board plough or, less economically, by the use of the hoe. The furrow is generally·about two feet deep and two feet wide ; the cane is in porous soils laid along the bottom of the furrow ; in clayey

soils the cane is often planted on the top of the furrow; a section of the field in the two cases will then appear as in *Fig. 41*. Where irrigation is used the furrow is made to follow the contour of the field.

In some places, notably Barbados, Réunion, and Mauritius, the cane is planted in holes; these holes are from fifteen to eighteen inches long and eight to twelve inches deep and wide; the cane top or often two tops are placed in this hole and covered with a layer of soil; not infrequently the hole is filled with stable manure upon which the top is planted; in Mauritius it is customary to count 3000 of such holes to the acre. This method of planting is one that entails considerable manual labour, but in Mauritius it is not unjustly claimed that canes planted in this way have a secure hold on the soil and are less liable to be damaged in a strong wind than are the canes planted in furrows.

In Cuba and Barbados a system is common in which the canes are planted in holes made in the soil by driving in a crowbar.

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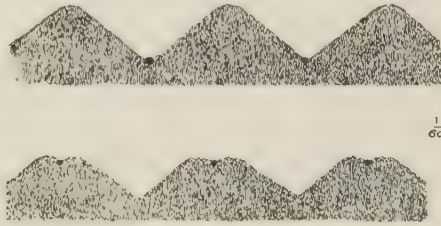
FIG. 41.

Amount of Seed Cane required per Acre.—This is, of course, dependent on the number of rows per acre, and whether the seed cane is planted in single or in double lines in the row. In an acre with rows five, six or seven feet from centre to centre the length of the rows is approximately 8740, 7280, and 6270 feet; taking the cane as weighing eight ounces to the running foot, there will be required 4370, 3640, and 3135 lbs. of cane respectively if the latter is laid in single rows.

Reynoso System.—The Reynoso system of planting cane frequently referred to in the literature of the cane consists, so far as the writer understands it, in planting the cane in parallel furrows spaced equal distances apart. In his classical treatise Reynoso lays stress on the necessity of a proper aëration and tillage of the soil, but his system, properly so called, consists of furrow planting as opposed to planting in squares, as was and still to a certain extent remains the custom in Cuba.

Zayas System.—This system, lately devised by Dr. Zayas in Cuba, consists in planting in rows up to twelve feet apart, and in the continuous cultivation of the soil. Dr. Zayas does not advise the use of artificial manures but of pen manure only; he also proposes a selective reaping of the crop, the immature stalks being held over. By the use of this system a much longer period of profitable ratoonage is said to be assured to the cane.

Width of Row.—In general it is the fertility of the soil that determines the most economical width of row; in very fertile soil, the rows are placed comparatively far apart to allow freedom of growth to the luxuriant crop, and conversely as the soil becomes less productive a narrow row gives more economical results. In practice the cane rows are from three to seven feet wide; in Cuba, according to Reynoso, the standard width is 1·70 metre (=5 ft. 6 in.), the rows being the same distance apart. Bonâme gives the average width of the cane row in Guadeloupe as 1·30 to 1·50 metre (=4 ft. 2 in. to 4 ft. 9 in.). The most economical width of row was the subject of inquiry at Audubon Park, where it was found that the narrower the row the greater was the purity of the juice and the yield of cane, but that in very narrow rows the increased yield of cane was barely sufficient to pay for the extra amount of cane required to plant up a field with narrow rows. Stubbs[2] suggests that that width of row which best admits of proper cultivation should be selected, and following on this argument, five-foot rows have been adopted at Audubon Park.

Source of Seed Cane.—In most districts it is the young immature top of the cane that forms the source of seed; the use of this is defensible on the grounds that this part contains little sugar, but much nitrogenous bodies and salts destined as food material in the early stages of growth; also the accumulated experience of planters generally points to this part of the cane furnishing the better seed. In Cuba, however, it is usual to employ the whole cane. In the Hawaiian Islands, many planters consider *lalas* make the best seed. Cane in those islands often stands long periods after flowering; the eyes at the upper joints sprout and grow to a considerable size forming a very short jointed woody piece of cane, locally called a *lala*.

Where the harvest of one crop and the planting of the next proceeds simultaneously, no difficulty in obtaining seed is experienced; when, however, planting and harvest fall in different seasons it is often necessary to *draw down* canes of age six months and upwards dependent on climatic influences so as to obtain seed.

In Louisiana, where it is necessary to carry over seed from the harvest towards the end of the year to the time of spring planting, seed cane is preserved buried in the ground (*windrowing*); or protected from the weather in *matelas*. In Java, the system of cane nurseries (*bibit gardens*) distinct from the plantations is in extended use; some planters there grow cane solely for the purpose of selling seed; these nurseries are often situated in the mountains as it has been found that such seed afforded some protection against sereh. A peculiar method in use in Ganjam is thus described by Subra Rao[3]. In July seed cane is planted in a seed bed, so close as to leave no space between the cuttings which are of three joints each. In the middle of August the cuttings which have now sprouted are transplanted to a nursery about five times the size of the seed bed; the nursery is laid out in furrows about eighteen inches apart.

In the following May the crop is cut down and used to plant adjacent fields or sold for seed to other cultivators, a portion being reserved to go again through the above cycle.

The writer has been informed that a similar system obtains in Java; in this case he believes that the seed cane is planted in small baskets packed close under shelters of the crudest description; these cuttings are carried to the fields and planted as soon as the seasonal rains have begun to fall.

Cultivation.—By cultivation is here meant the working of the soil and the keeping down of grass and weeds during the period between the planting of the cane (or *spring* of the ratoons) and the harvest of the crop. In districts dependent on manual labour the operations include *weeding and moulding* and *forking*.

British Guiana.—In British Guiana and in other places dependent on manual labour a typical routine is as follows:—Shortly after a crop of cane has been taken off, the soil in between the rows of cane is turned over with agricultural forks; this process is known as 'forking banks;' in about a month the weeds and grass that have sprung up are cut down with the cutlass, the machête or the hoe, a process which will have to be repeated every one or two months until the canes are of such a height as to keep down the growth of weeds. Simultaneously with the weeding earth is hoed over the cane row, the process being known as *moulding;* in some parts, especially in Eastern Asia, this moulding is carried to an extreme pitch, the cane rows being earthed up to a great extent. In some places, as in Cuba under the old régime, the keeping down of the weeds formed the only cultivation that the cane received.

Louisiana.[*]—Stubbs[4] thus describes the routine followed at Audubon Park in Louisiana:—" The land is broken flush with a large plough, pulverized with a harrow, and bedded with two-horse ploughs. The rows are opened with a double mould-board plough, cane planted and covered, and middles broken out with the double mould-board plough. The quarter drains are opened six inches between the middle of the rows and the ditches are cleaned. At the proper time the cane is off-barred with the two-horse ploughs, scraped with hoes, and when large enough is fertilized by scattering the mixture across the open furrows and narrow ridge of cane. The dirt is returned as soon as fertilizer is applied, the middles broken out deep and clean, and the turn ploughs sent to the barn to remain until the next season. The disc cultivator, with the three small discs on either side, is used for throwing dirt to the cane at the first working, and the middle or diamond cultivator for breaking out the

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[*] To those familiar with hand husbandry only, this description requires some amplification. In the Hawaiian Islands *off-barring* is termed *slicing the ratoon row*, and this term conveys a better impression of the process; the instrument used is a disc plough of the type shown in *Fig. 30*; it is drawn alongside the ratoon row cutting through the old roots, throwing the dirt away from the row and leaving an open furrow alongside the cane; after the furrow has been exposed for two or three days the dirt is thrown back to the row by the aid of disc implements.

It should be noticed that animal power cultivation does not altogether dispense with manual labour; in all cases the weeds and grass in the row itself have to be cut down by hand tools.

middles. In the second and third cultivations two middle discs replace the three used in the first, and are set to such an angle as to throw the desired amount of dirt to the cane, and are followed each time by the middle cultivator, thus completing the work with the two implements. At 'lay-by,' the large or ' lay-by ' discs are used, followed by the middle cultivator with its two front shovels removed. By proper adjustment of the two instruments, ridges of any desired height can be made and the cane properly laid by."

Hawaii.—On the irrigated plantations mechanical cultivation is not possible and weeds have to be kept down by hand ; on a rainfall plantation the grass is mainly kept down by the use of disc cultivators run astraddle the row and turning the soil away from the cane ; this leaves only a small area to be hand hoed. After the first hoeing, fertilizer is scattered between the rows and incorporated with a tine cultivator or other implement, the soil being stirred as much as possible. On ratoon fields, the first operation after taking off the crop is usually slicing the row ; manuring follows at once after which the soil is thrown back to the row by a disc cultivator run astraddle the row. A stubble digger (an appliance consisting essentially of a series of small tynes revolving on an axle as the carriage is drawn along), is then passed over the row so as to mix the manure and soil and loosen up the latter ; weeds between the row are kept down as described above.

Cuba.—F. S. Earle[5] gives the following account of a method of cultivation advocated by the Cuban Experiment Station as the most practical under the conditions there :—

"The system recently advocated by the Cuban experiment station, while it has not yet stood the test of long continued use, promises to solve satisfactorily the question of continued production of profitable stubble crops. It is as follows :—Plough the land intended for fall cane in the winter or spring. Plant to velvet beans in April or May. Plough these under with a disk plough in August and September. Harrow two or three times with the disk harrow. In October open deep planting furrows with the sulky double mould board plough, spacing them about seven feet apart. Scatter tankage and potash or some similar complete fertilizer carrying about equal parts of nitrogen, phosphoric acid, and potash in the bottom of the furrow, at the rate of 500 lbs. per acre. This is best done with a two-horse fertilizer drill. A small cultivator shovel attached at the rear of the drill will serve to mix the fertilizer at the bottom of the furrow. Now drop a continuous row of seed cane in the bottom of the furrow. It is best to select plant cane or vigorously growing stubble for seed. Using that from old worn-out stubble fields is inadvisable, as it will make a weaker, less satisfactory growth. Cover with the disk cultivator, setting the gang to throw more or less dirt, according to the condition of moisture. If the ground is moist, germination will be prompter if the cane is not covered more than two or three inches. If it is dry, it is necessary to cover six or eight inches deep to prevent the drying of the seed canes. In from one or two weeks, or just as the canes are peeping through the ground, harrow the field thoroughly with the smoothing harrow running lengthwise of the rows. This will kill any small weeds that may be starting, and will freshen the surface of the soil and greatly aid germination. When the young plants are well up so that they show from one end of the row to the other, begin cultivating with the ordinary riding two-horse corn cultivator, of course straddling the row so as to cultivate two rows at once. The seven foot rows are so wide that there will be a strip in the middle not reached by the cultivator. This can be finished by the ordinary walking

cultivator of the planet Jupiter type, or the narrow cultivator blades may be removed from the regular cultivator, and eight-inch cutaway sweeps be bolted on instead. These will have a wide enough cut to meet in the centre, and as thus rigged the same implement makes a good middle cultivator. Cultivation should be repeated throughout the winter as often as is needed to keep down all weeds and maintain a dust mulch. Before spring the growth of the cane will be so great that the row can no longer be straddled, and the middles only can be cultivated. In April or the first part of May sow cow peas broadcast in the middles, cover them with the cultivator and the work is finished. Up to this point the plan does not differ materially from the ordinary system except that the use of the riding corn cultivator, which works so close to the row, makes it possible to almost dispense with the expensive hoe. It is only the few weeds and bunches of grass that come up directly in the row that have to be cut with the hoe, or better still be pulled by hand. The line of cultivation thus outlined will leave the land practically level. This is right for the red lands, since they have natural under-drainage, but in the wetter black it should be modified by using disk cultivators which ridge up the row as in Louisiana.

"As soon as the cane is cut, take an ordinary horse rake and drive so as to cross the cane rows, raking the trash from one middle and dumping it in the next one. This quickly and cheaply clears half the ground so that it can be ploughed and cultivated, and it provides a double mulch of trash for the other half which makes it so thick and heavy that practically no grass or weeds can come through, and these middles will require no further attention for the season. Now plough the cleared middles with a two-horse turning plough, throwing the dirt away from the cane. Run the last furrow up as close to the cane stubble as possible. You will not hurt the roots. They all died when the cane was cut, and the new ones will form as the new shoots of cane begin to grow. If fertilizer is needed, it can now be applied in this open furrow next the cane. On most lands, however, it will only be necessary to use fertilizer every third or fourth year. Do not leave the furrow next the cane open any longer than is necessary, but work the dirt back with the cultivator, using some implement that will throw a little dirt back over the stubble. Keep these alternate middles well cultivated until the beginning of the rainy season and then sow them down to cow peas. This will be found much cheaper than the ordinary plan of going over all the surface of the ground two or three times with hoes, and it leaves the stubble cane in even better cultural condition than the plant cane, for one side of each row is thoroughly cultivated, while the other side is protected by a heavy mulch of trash, which serves perfectly to retain moisture. The next year, of course, the middles are reversed so that all the soil is thoroughly aërated, and pulverized every two years. And yet only half of it is exposed to the depleting influence of tillage while all the trash is retained on the land and is ultimately incorporated with it to add to its supply of humus, a substance so necessary for successful tropical agriculture."

Fig. 42 shows a typical Cuban plough preparing land for planting; this photograph was taken in 1909, but the steam gang plough is fast superseding the ox.

Strait Settlements.—The process of 'banking up' which seems peculiar to Eastern Asia is thus described by F. Campen[6]:—

"Whenever the field gets grassy it is weeded and heavily moulded at the same time, and then given time to grow, until the general stand of canes is from about three to four feet high, when the time has arrived to give it the first banking, which is done as follows:—The men go to the field and each of them takes a row, which he weeds and very particularly takes off all trash, especially all the small leaves at the bottom of the cane stools. After this, with a dry cane blade, he ties the bunches together in such a way that each cane stool is separate by itself, and after having done this he takes the hoe and makes a drill between the cane rows,

doing this in such a way that, when lifting the earth he places it round the cane row, taking care that everything is even, and the work when finished has the look, as if the shovelman in Demerara had been digging a drill, a foot deep by a foot broad, with the difference however that instead of having thrown the earth on the so-called trash bank, he has spread it all over and about the canes, covering everything lightly from cane-row to drill. When so finished this will give you a cane row or bank, as it is called here, with a kind of rough drill, of a foot by a foot, on each side of it. As to the drills no particular neatness or paving is required as long as they are well in the middle and have the required depth and breadth.

"Nothing more is now done to the fields until the canes, after a couple of months, have grown a little more, and so to say have from four to six joints, when the same performance is gone over again, only with the difference that the labourers, when taking out another foot of earth from the same old drill, pack it on and between the cane stools, and press it down and against them with their feet, so that in time the canes have something to support them, and are able to grow upright.

"The appearance of this last work or bank, when properly finished must be something similar to an umbrella or the hut of a Zulu, and the more earth that has been put around and between the stools the better it is; also the distance from the top of the earth packed around the cane stool to the bottom of the drill must be not less than three and three-quarter feet."

Trashing.—By this term is meant the removal of the dry and dead leaves at intervals during the growth of the cane. The benefits or otherwise of this practice are a matter of much dispute. The rationale of the process is:—

1. The removal of the dead leaves exposes the cane to light and air and hastens its maturity.

2. The dead leaves afford harbouring places for injurious insects.

3. Water lodging in the space between the leaf sheaf and the cane promotes the development of the eyes and the aërial roots to the detriment of the cane.

4. The dry leaves being placed on the ground act as a mulch and help to retain soil moisture.

On the other hand it is claimed that the ripening effect is small, that the labourers in passing between the canes do much damage, that many leaves that can still carry on their functions are pulled off along with those actually dead, and that when these are pulled off some damage is done to the cane, preparing the way for fungus attacks. The matter has been put to experimental test; Bonâme[7], who writes strongly in favour of the process of removing the *dead* leaves, found the following results:—

1. Only completely dry leaves removed.

2. Canes trashed *a blanc*, *i.e.*, a certain number of green leaves removed. (This would be called *bleeding the cane* in the West Indies.)

3. No trashing.

	1		2		3
Degree Beaumé	8·10	..	7·50	..	7·70
Sugar per cent...	13·40	..	11·60	..	12·20
Glucose	1·30	..	1·56	..	1·29

No record of the weight of the crop is given.

Eckart[8] found very different results in Hawaii. In a very complete series of tests carried on at the Experiment Station there, the plots that were not trashed gave uniformly a higher yield of cane and a sweeter and purer juice.

The Disposal of Trash.—As an average of the data due to Maxwell, and already quoted, each ton of cane stalks produces, in the leaves and waste matter, 1·95 lbs. of nitrogen; let this nitrogen be valued at 7·5 pence per pound, so that its value is then per ton of cane stalks 14·6 pence. A crop of 40 tons of cane will then contain in its waste matter nitrogen to the value of £2 8s. 8d. When the trash is, as is often the case, burned off, this relatively enormous quantity of nitrogen is lost. To agriculturists accustomed

Fig. 42.

only to European farming practice this custom is barely creditable. It is defended on the following grounds :—

1. The cost of cane cutting is decreased if the fields are fired immediately before harvest. In Demerara, where labour is very cheap, the saving is from five to six shillings per acre.

2. The expense of burying the trash and of removing it from the cane rows is saved.

3. The combustion of the trash also destroys fungus spores and noxious insects. According to Dr. Perkins, however, in Hawaii the burning destroys the parasites of the leaf hopper, the latter escaping by flight.

4. Fields in which the trash has been burnt off allow the ratoons to 'spring' to better advantage; this effect is probably due to the setting free of the ash constituents of the trash.

These reasons are apparently considered to outweigh the loss of nitrogen; it must not however be forgotten that the burying of the trash puts into the soil large quantities of humus, the importance of which in increasing the water holding capacity of the soil and enabling the canes to pass through a period of drought is very great.

Wrapping[9].—This process, the reverse of trashing, seems to be confined to portions of Southern India, where in parts, the dead leaves are wrapped round the stalk; this process is partly intended as a protection against jackals and partly to diminish rooting and sprouting habits.

Selective Harvesting.—In healthy cane there is a point at which the cane contains a minimum of, or even no, reducing sugars and when it is at its maximum purity; after this point there is a breaking down of the cane sugar into reducing sugars and the cane is over ripe. In some varieties this reversion is very rapid and it is also influenced by climatic conditions; it is then a matter of great importance to harvest a field of cane at the time of its maximum purity; the system under which this selective reaping is pursued is thus described by Prinsen Geerligs[10] :—

" The cane fields are divided into plots which have been planted and manured at the same time and in the same way. After ten months of growth take from each plot 40 normally grown cane stalks, and mark and number them. Every fortnight one cane stalk is cut from each one of the stools and the bundle carried to the laboratory, where the green top end is removed and the canes are measured, weighed, and crushed in a small test mill, after which the juice is analysed. The analytical data from each analysis of the test plot are entered down, so that an increase of sucrose content or purity, or a falling in them, can be detected at once. As soon as the sucrose content or purity cease to augment, the cane of the plot under review has attained its point of maturity, and should be cut in order to prevent deterioration by too long standing in the field."

In some instances this process is followed in conjunction with a portable travelling field laboratory.

Ratoonage.—The period to which canes are allowed to ratoon varies in different countries; in Java the great majority of the crop is plant cane only; in Louisiana plant and first ratoons are grown; in Mauritius it is customary to grow up to third ratoons; in Cuba, the West Indies and in British Guiana fifth ratoons are not uncommon, and fields can be found that have not been replanted for a generation; in Hawaii canes are seldom allowed to grow beyond second ratoons. The economic limit to which canes can be ratooned can only be determined by those on the spot and familiar with local conditions. Long continued ratoonage has been connected with the prevalence of various forms of root and root stock diseases, as in this case the cane fungus has a continuous habitat.

Cutting Back.—The flowering season in the Hawaiian Islands is during the months of November and December. Cane that has been cut early in the year will flower that same year and will have to be harvested after a twelve months' growth; such cane is termed *short ratoons*. By allowing such cane to grow till June and then cutting it back, it can be carried over the flowering season of that year and will flower in the November of the following year, thus giving a 17 to 18 months' period of growth from the time it was cut back till it flowers, and a total period of growth of not less than two years by the time it is harvested. Such cane is called *long ratoons*.

Period of Harvest.—The time of harvest in the more important cane growing areas is as shown below :—

British Guiana.—September to December.
Cuba.—December to June.
Java.—May to November.
Mauritius.—August to December.
Louisiana.—October to January.
Hawaiian Islands.—December to September.
Peru.—October to February.
Brazil.—October to February.
Argentina.—June to October.
Egypt.—December to March.
Queensland.—June to November.
Mexico.—December to May.
Philippines.—September to March.
West Indies.—January to July.

Influence of Arrowing on the Cane.—Arrowing marks the end of the vegetative period of the growing cane. It has been thought that arrowing had an influence on the sugar content of the cane; definite experiments by Harrison[11] and by Prinsen Geerligs[12] have shown that this belief is unfounded. After the cane has arrowed no further formation of sugar takes place, but an elaboration of that already formed obtains with an increase in the cane sugar content and in the purity; eventually however the cane dies down and then a breaking down of the cane sugar occurs. The time to which cane can be left standing after arrowing is very variable and is dependent on variety and climate. In the Hawaiian Islands cane may remain as long as six months after arrowing, before deterioration sets in.

Yield of Sugar per Acre.—The yield of sugar per acre is determined by the fertility of the soil, by the action of fertilizers, by climate, by variety, by the efficiency of the cultivation, and by the efficiency of the manufacturing processes. Without doubt the highest returns have been obtained on the heavily fertilized, systematically irrigated, porous, volcanic, basaltic soils of the Hawaiian Islands; as much as 30,000 lbs. of sugar have been there

obtained per acre of land over large areas and returns of 20,000 lbs. are not unusual; on an average, however, the irrigated plantations there yield about 12,000 lbs. per acre from a crop of plant cane and long and short ratoons. In Java, the average return has reached 11,000 lbs. per acre and returns of this magnitude are also known in Peru. A Consular report gives the production in Cuba for the year 1909 as 14,214,946 long tons of cane from 849,000 acres, or 16·7 tons per acre; with a recovery of 10 per cent. on weight of raw material this would indicate a return of 3700 lbs. per acre. Elsewhere a return of 4000 lbs. per acre would seem to be also above the average.

Chemical Selection of the Cane.—By continually selecting for seed beets of high sugar content, the richness of that plant in sugar has been greatly increased; a similar process is not possible with the cane owing to its asexual process of propagation. The records of more than one experiment station contain accounts of attempts to improve the cane by the selection of cuttings from sweet canes, but the earlier results were inconclusive and contradictory. Definite results have been obtained by Kobus[13] in Java, who thus summarizes the results of his experiments :—

"Different stalks of the same sugar cane plant vary widely in sugar percentage even when they are of the same age. Consequently we founded the chemical selection on the analysis of the juice of the whole plant and not on that of single cane stalks.

"The variability of sugar percentage of various sugar cane varieties is very different. Those grown from cane seeds do not vary so much as the old varieties.

"The juice of the heavier plants is richer in sugar than that of the lighter ones, and those plants that have the richest juice are the heaviest. Plants grown from cuttings derived from canes rich in sugar are heavier and contain more sugar than those grown from average plants or from plants poor in sugar.

"When we select the richest canes from the descendants of canes that were already rich in sugar, and also the poorest canes from the descendants of poor canes, and go on in this way for some years, we very soon arrive at a considerable improvement in the rich canes (40 per cent. in five years) and a heavy depression in the descendants of the poor ones (60 per cent. in five years). The descendants of cuttings grown from once selected canes remain richer in sugar for at least four generations, and show as an average of forty experiments only a very small decrease.

"The correlation of a high sugar percentage in the juice and a heavy weight of cane plant simplifies the method of selection in a remarkable way. It is sufficient to select those 20 per cent. that are the heaviest, *i.e.*, the strongest tillered plants of the cane field and plant the cuttings of one-half of these, viz., of those richest in sugar.

"We proved that differences in the juice of the descendants of rich and of poor canes are already visible at an age of thirty weeks, and that it is possible to perform the selection at that age in the fields we use in Java for the propagation of cane cuttings. Highly selected canes of twenty weeks did not show any difference in the juice of the rich and the poor plots."

Field Ledger.—A sugar plantation being often a self-contained unit affords a unique opportunity for the systematic accumulation of valuable data which in a few years form a valuable guide ; such data may conveniently be entered in a ' Field Ledger,' using one double page to each field and one line to each year or crop ; such a ledger should contain columns for entering up the following data, the exact mode of bookkeeping followed being governed by local considerations :—Year ; rotation (plant or ratoons, green crop, &c.) ; variety ; tons of cane and sugar per acre ; % sucrose in cane and purity ; nature of soil ; cultural operations ; prevalence of pests and diseases ; manure applied ; lime applied ; agricultural and fertility (citric acid) analyses of soil ; inches of rain and irrigation water ; mean temperature ; date of planting, harvesting and period of growth ; date of arrowing.

REFERENCES IN CHAPTER VIII.

1. *I. S. J.*, 66 and 67.

2. Stubbs' *Sugar Cane*, p. 113.

3. *Dept. of Land Records and Agric. Madras II.*, p. 202.

4. Stubbs' *Sugar Cane*, p. 145.

5. *Southern Agriculture*, pp. 128-135.

6. *S. C.*, 314.

7. *Cultur de la Canne à Sucre*, p. 129.

8. *Bull.* 25, *Agric. H.S.P.A.*

9. *Loc. cit.*, 3, *supra*, 10.

10. *I. S. J.*, 68.

11. *S. C.*, 294.

12. *S. C.*, 346.

13. *I. S. J.*, 90 and 91.

CHAPTER IX.

THE PESTS AND DISEASES OF THE CANE.*

The cultivation of the cane is in many places one continuous struggle against its pests and diseases; this is so much so that the time of many experiment stations is occupied in studying and devising remedies against the cane's enemies. Within the limits of a manual such as the present only the fringe of the subject can be touched on; more complete details will be found in Van Deventer's ' *Die dierlijke Vijanden van het Suikerriet op Java*,' in Went and Wakker's ' *Die Ziekten van het Suikerriet op Java*,' in the ' *Memoirs of the Department of Agriculture in India*,' in the *West Indian Bulletin*, in the *Sugar Cane* and *International Sugar Journal*, in the Java *Archief* and in the Bulletins of the *Hawaiian Sugar Planters' Association*.

Abnormalities in Canes.— Peculiar canes with aborted joints, with a superabundance of eyes, with absence of eyes, with excessive development of the woody tissue, and with albino leaves, are sometimes noticed; the phenomena have little interest other than academic. Some varieties show these features more frequently than others, and the writer's clinical observations lead him to think that temperature variation may be a predisposing cause for these abnormalities.

Weeds particularly connected with the Cane.—Certain weeds have been noticed as associated with the cane, though their presence is not in any way directly connected with the cane. Amongst these may be mentioned a succulent herbaceous annual *Alectra brasiliensis*, whose roots penetrate the cuticle of the cane and destroy it. This weed has been named the ' cane killer' in Trinidad. In India a weed, *Strigea lutea*, and similar to the 'broom rape,' is known as a frequent inhabitant of cane lands; the 'lantana,' a woody shrub belonging to the *Verbenaceæ*, is known throughout the tropics as a pestilent plant, rapidly taking over land temporarily abandoned; it is particularly obnoxious in Mauritius and the Hawaiian islands. In the latter district it has been controlled by Koebele in an elegant way, namely by the importation of sundry insects with a specialized habit of feeding on the leaves or of ovipositing in the flowers and seeds.

Mammalian Pests.—Excluding purely isolated cases of occasional damage by the larger animals, it is only rats, hares and jackals, that can be regarded as cane enemies. Rats are cosmopolitan in their distribution, and not only destroy cane, but also cause considerable damage to parapets and drains. Hares are known as a cane pest in India and in Mauritius, in the latter place their depredations being considerable. Jackals are confined to

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* Kirkaldy (Bull. 8, Ent. H.S.P.A.) has given recently a complete bibliography of cane pests, enumerating in all 400 species noted as attacking cane.

India where the Chinese cane (*Saccharum sinense*) is said to be so hard as to resist their teeth.

Lepidopterous Pests.—The *Lepidoptera* (moths and butterflies) that may be classed as cane pests fall into two main divisions, those that cause damage by the caterpillar eating the stalk, and those where the leaf is selected as a food material; in addition certain *Microlepidoptera* attack the cane, principally at the eye. In the Hawaiian Islands these last are known as 'bud worms.'

The stalk-eating caterpillars are known as 'borers';[*] they are of wide distribution, and annually cause immense damage. Following on their mode of attack they are classed as 'top,' 'stem,' and 'root' borers; in *Figs. 43* and *44* are given after Kruger diagrams illustrative of the mode of attack of a stem and of a top borer.
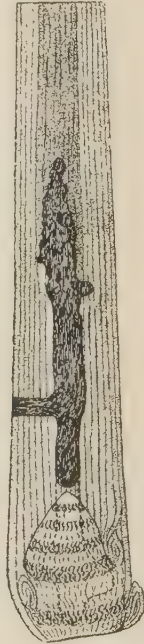
FIG. 43.   FIG. 44.

Below is given a list of the known cane borers, included in the *Lepidoptera*.
TOP BORERS.

Scirpophaga auriflua. The white borer of India.
Sc. monostigma. The black spotted borer of India.
Sc. intacta. The white borer of Java.
Sc. chrysorrhoea. India.
Chilo infuscatellus. The yellow borer of Java.
Grapholitha schistaceana. The grey borer of Java.

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[*] The term *borer* is also applied to several coleopterous (beetle) insects attacking the cane, and mentioned subsequently.

FIG. 15.
BLACK
TANNA.

$\frac{2}{3}$
SIZE

PLATE VIII

STEM BORERS.

    Diatræa saccharalis. The West Indian borer.

    D. striatalis. The grey stem borer of the East Indies and Australia.

    Chilo auricilia. The gold fringed borer of India.

    C. simplex. India.

    Nonagria uniformis. The pink borer of India.

    Anerastia ablutella. The green borer. India.

    Castnia licus. The large moth borer of South America.

    Sesamia nonagrioides. The purple borer. Java, East Indies, Spain,
        Portugal, North Africa, Madeira, Mauritius, Madagascar.

ROOT BORER.

    Polyocha saccharella. India.

All these borers have a very similar mode of attack; the female moth lays its egg on the leaf of the cane; the caterpillar, on emergence, attacks either the stem, generally at the eye, or else the terminal point, and eats its way into the cane. When in the cane it often tunnels the whole length of the stalk; eventually the perfect insect emerges from the cane.

When young cane shoots are attacked, especially by the top borer, the death of the stalk results; in older cane, especially when attacked in the stem, the damage may not be so complete.

The Borers have been studied in great detail in many cane growing districts; full accounts of those that occur in Java are given by Kruger[1] and Van Deventer.[2] Maxwell Lefroy[3] has described the West Indian Borer, and the Borers as they occur in British India[4]; Oliff[5] has described the Borer of New South Wales, and Bojer[6] the Borer in Mauritius.

A short account of the West Indian Borer, as described by Maxwell Lefroy,[3] is appended, as typical of these pests :—

    " . . the eggs are flattened oval, and slightly convex, about $\frac{1}{28}$ of an inch in length; they are laid in clusters on the leaf of the cane, the number being very variable, lying between 4 and 57, and being generally from 10 to 30. The eggs when fresh are light yellow; in 36 hours a tinge of orange appears, and eventually they turn orange brown; in the final stage the centre of the egg becomes black. If the eggs are laid on young cane the part attacked is the axil of the leaf or the leaf itself; in the case of older cane the part attacked is the joint, the caterpillar eating its way into the cane, and making tunnels up and down the cane, from which it eventually emerges in from 30 to 35 days. The period of pupation, which takes place within the cane, is six days, after which the perfect insect emerges. The moth is inactive by day, and living only four days lays in that time from 100 to 300 eggs."

In *Figs. 45* and *46** are shown the larva and moth of the Borer *Diatraea striatalis*, and in *Figs. 47* and *48** the larva and moth of *Sesamia nonagroides*. The eggs of the first-mentioned are shown in *Fig. 49**; at *a* are fresh eggs, at *b* eggs just before emergence of the caterpillar, at *c* and *d* are eggs parasitized by *Ceraphron beneficiens* and *Chaetosticha nana*. *Fig. 50** shows the quite different

* See *Frontispiece.*

egg mass of *Scirpophaga intacta;* all these are after Van Deventer. The leaf-eating lepidopterous pests, are neither in the extent of their destructiveness nor in the permanency of their attack to be compared with the Borers; their attack seems to be sporadic and to rise and fall with many factors. Thus the 'army worm' (*Leucania unipuncta*) is known to attack cane and corn after floods which have forced it to leave its usual habitats. The damage is chiefly to young cane, the leaves and not the stem being attacked; except in severe cases the cane recovers, and suffers only a temporary check in growth.

Coleopterous Pests.—The *Coleoptera* (beetles) are equally destructive with the *Lepidoptera*, and, as with the latter, it is chiefly the larvae that do the harm, although in some cases it is the perfect insect that attacks the cane. The term ' Borer ' is also applied to some of the beetles, and in fact, in the Hawaiian Islands, this term is confined exclusively to the ' Weevil Borer ' (*Sphenophorus obscurus*); an allied insect, *S. sericeus*, is also known as a Borer in the West Indies.

Amongst the major coleopterous pests of the cane attention may be called to the Walwalan Beetle (*Apogonia destructor*) of Java, the West Indian Root Borer (*Diaprepes abbreviatus*), the Cane Grub (*Lepidoderma albohirta*) of Australia, the Louisiana Beetle Borer (*Ligyrus rugiceps*), and the Weevil Borer (*Spenophorus obscurus*) of the Hawaiian Islands, Fiji, Australia, and New Guinea. The damage done by the first four above-mentioned pests is due to the larva, which passes its life underground, eating the roots; the fifth is a stem borer. *Figs. 51, 52,* and *53,** after Van Deventer, show a piece of soil containing the grubs and the larva and perfect insect of *Apogonia destructor*.

The life history of the West Indian Root Borer has been worked out by the Rev. N. B. Watson,[7] whose description of this pest is appended :—

" In August and September the perfect insect lays its eggs on the upper surface of the leaves, and after ten days the grub emerges and falls on the ground, immediately burrowing into the ground in search of food. The grub remains in the soil for 312 days, eating the roots of cane, sweet potato, &c., and then pupates, the perfect insect emerging in fifteen days to repeat the same cycle. The grub at first is only $\frac{1}{18}$ inch long, reaching at maturity a length of one inch.

In *Fig. 54** is shown the Weevil Borer, and in *Fig. 55** a typical piece of damaged cane. The life history of this insect as it occurs in the Hawaiian Islands is thus given by Koebele[8] :—

" The female beetle is easily separated from the male by its longer, smoother, and more slender beak, and its pointed terminal segment. She lays her eggs consecutively, probably four to eight each day, but less than this toward the end of the period of six or eight months during which she continues to lay. When the egg is laid in the cane from the outside, this is done from under the sheath, which the beetle can brace against; with the prominent saw-like movable teeth laterally she first begins to eat out the hole until softer ground is struck, so to speak, when she will force the work, moving the head up and down as well as sideways until the whole length of the beak is buried. Upon soft parts on split cane this operation

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* See *Frontispiece.*

takes from 1¼ to 2 minutes; no doubt much longer in boring through the hard epidermis, probably hours. After the hole is completed the beetle walks up and inserts the ovipositor, remaining in this position from 4 to 6 minutes. The bone coloured egg is found embedded parallel to the fibres. It is about 2 mm. long by ¾ mm. in thickness and slightly bent. The hole close to this is filled in with mucous matter intermixed with particles of fibre. Repeated observations show these eggs hatch in six days. The newly-hatched larva is at first transparent as the eggs of the latter production, the first being of a more opaque colour as also the young larvae, with the head of a darker yellow colour. We found that the young larva went out in the same direction as fibres about one-eighth of an inch deeper, having made a hole one inch long in from four to five hours. As the larva increases in size its power of boring becomes more rapid. A half grown specimen traversed a piece of cane six inches in length, from one end to the other, in three days."

Other coleopterous pests of less importance are the 'Bibit Kever,' *i.e.*, cane top beetle (*Holanaria picescens*), the mature insect of which attacks the eyes of the cane when used as seed, and several 'Leaf Miners' such as *Hispella wakkeri*, the larvae of which feed on the cane leaves.

The well-known and widely distributed 'Shot Borer' beetle (*Xyleborus perforans*) perhaps confines its attention to dead and damaged cane and is not to be regarded as a serious pest.

Rhyncotous Pests.—The *Rhyncota* are a great order of insects characterized by the development of the mouth parts into an organ known as the beak or rostrum, adapted for the sucking of vegetable and animal juices; the phases of insect life known as lice, blights, blast, scale and bugs (in its English sense) include many insects of this order. A large number (upwards of twenty in Java alone) have been noted as cane pests. Several historical epidemics of the cane have been due to the *Rhyncota*, and of these may be instanced that of the Cane Fly (*Delphax saccharivora*) in the West Indies in the beginning, that due to the *pou-à-poche-blanche** in Mauritius, about the middle of the nineteenth century, and that in the Hawaiian Islands due to the Leaf Hopper (*Perkinsiella saccharicida*) at the beginning of the twentieth century. To these may be added the more recent epidemic of the Frog Hopper (*Tomaspis posticata*) at present (1909) prevalent in Trinidad.

Although individually these insects are very small, yet the numbers in which they occur, and the rapidity with which they multiply is the occasion of great damage; for these same reasons they are indifferent to any but the specialized means of control described below.

In *Fig. 56†* is shown a leaf of the cane infected by an aphid (*Aphis sacchari*) and is illustrative of the great numbers of these, and of allied pests, that may be present in a small space.

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* The true *pou-à-poche-blanche* is a coccid (*Icerya scychellarum*); a second coccid (*Pulvnaria iceryi*) was also present in the original Mauritius epidemic. The term pou is also applied to a mealy bug (*Dactylopius calceolariæ*); this pest has also been confounded with the white louse of Java (*Oregma lanigeri*) which is however an aphid and entirely distinct.

† See *Frontispiece*.

Orthopterous Pests.—The *Orthoptera* do not include any of the major pests of the cane; the one of this order that causes most damage is probably the Mole Cricket[9] (*Scapteriscus didactylus*) in Porto Rico where, besides attacking cane, it is a general plant enemy. The fully developed insect is about $1\frac{1}{4}$ inches long. The damage done to cane is by the attacks of the perfect insect in search of food. The greater part of the life of the insect is passed underground feeding on the roots of cane and other plants; it emerges at night, and then feeds on the crop above ground. Its attacks continue the whole year round. It has been observed to attack plants continuously, and beyond the demands of its appetite. This insect committed great damage in S. Vincent about 1830, and in Porto Rico became a dangerous pest in 1876, after the destruction by a hurricane of its most effective enemy, the blackbird, this forming an interesting illustration of the effect of disturbance of the 'natural balance.' Its damage is greatest in moist sandy soils; in dry soils it does not thrive, and saturation and extreme dryness are conditions inimical to its development.

Another Mole Cricket (*Gryllotalpa africana*) in the Hawaiian Islands not only injures the cane directly, but also does considerable damage to the irrigation ditches by means of its tunnels.

Amongst other pests of this order may be mentioned the white ants (*Termes taprobanes*) of India, which, according to Hadi, attack the cuttings of seed cane and less frequently the young shoots shortly after germination. The insects known as 'thrips' or 'bladder feet,' which are sometimes included in the *Orthoptera*, are also known as a pest of the cane in Java.

Acarid Pests.—Mites are a form of life frequently found on canes; the damage done to the cane is, however, in general small. A serious amount of damage was done in Queensland in 1876 by a mite, *Tarsonymus bankroftii*[10]; the disease was then known as 'Cane Rust'; this mite is also present in Java, where it does a certain amount of damage, and has also been noted in Barbados. Mites may also be considered as beneficial, since Ormerod[11] has observed the parasitization of the eggs of the West Indian Borer by this form of life.

Worms.—Certain nematode worms have been connected with cane damage, particularly the varieties *Heterodera javanica* and *Tylencus sacchari* in Java. They have also been much studied by Cobb,[12] but that they are to be classed as a cane pest is doubtful.

Control of Cane Pests.—The control of cane pests is mainly divided into two parts—their systematic destruction by methods referred to below, and the prevention of their introduction from foreign countries by a strict system of quarantine. The methods of systematic destruction employed vary with the pest, and below are some accounts of the principal systems in use.

1. *Poisons.*—The use of poisons is practically limited to the destruction of rats. The poisons chiefly employed for this purpose are preparations of strychnine, arsenic, phosphorus, and barium; bread, grains, bananas, and molasses are used as food media upon which the poisons are distributed.

Leaf-eating caterpillars are in some instances destroyed by dusting the leaves of the plants upon which they feed with sundry arsenical preparations, of which those known as 'Paris Green' and 'London Purple' are mostly used. Leaf-eating caterpillars are not amongst the most serious pests of the cane, and in practice it would be impossible thus to control them on a large estate.

2. *Collection by Hand.*—In districts where labour is plentiful and cheap, a diminution of the insect pests is obtained by hand collection. This collection takes the form of cutting out the 'dead hearts,' *i.e.*, the young cane attacked by borers, and the collection of the eggs of the moth laid on the leaves of the cane. The children of the black or Asiatic labourers forming the bulk of the labour supply of most sugar producing districts can readily be trained to perform this work. In the collection of eggs it is of importance that the parasitized
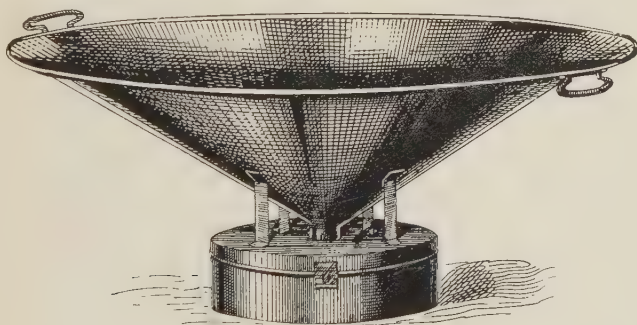
Fig. 57.

eggs be not destroyed. Following the advice originally given by Zehntner the eggs should be placed on a dish surrounded by a layer of molasses; the parasite from parasitized eggs emerges as a perfect insect and is able to escape, the molasses preventing the escape of the caterpillar from the unattacked eggs.

The night-flying coleopterous and lepidopterous insects can be captured by exposing lamps in infected areas; these lamps are exposed over trays of molasses which prevent the escape of the insect. For the capture of the Wawalan Beetle (*Apogonia destructor*) of Java, Zehntner[2] has devised the trap shown in *Fig. 57*, which is exposed under a lamp at night during the time that the beetles make their nuptial flights.

The employment of bait as a means of attracting insects is also in vogue in the Hawaiian Islands, and in Fiji it has been observed that the Weevil Borer is attracted by sour cane; Koebele[3] records that in Fiji, with the help of seven little Indian girls, he has thus collected 16,000 beetles in four

hours, and that there systematic collection over three years resulted in the almost complete disappearance of the pest. Similarly, S. M. Hadi[13] states that the white ant is in India attracted by dung which is purposely placed on the cane fields as a means towards the collection and subsequent destruction of the insects.

3. *Rotation of Crops.*—This has been recommended by Watson[7] as likely to diminish the prevalence of the West Indian Root Borer (*Diaprepes abbreviatus*), and amongst crops not attacked he mentions ochra, cassava, yams, eddoes, woolley pyrrol, pigeon pea, bonavist and rouncival beans.

4. *Use of Substances objectionable to Insects.*—Wray states that cane tops soaked for a few minutes in water tainted with petroleum are not attacked by ants, and S. M. Hadi[13] mentions the use of mustard cake and assafœtida by the ryots of India for a similar purpose. Naphthalene[9] has been used similarly to impregnate the ground to repel the mole cricket in Porto Rico.

5. *Use of Insecticide Washes.*—Spraying as a means of the destruction of insects is only effective with small crops grown on a restricted area, and has but a limited use with the sugar cane. It has been employed chiefly in connection with hemipterous pests, such as the Aphis and Mealy Bugs. Icery, in Mauritius, employed a wash formed by boiling lime and sulphur as a means of destroying the pou-a-poche-blanche ; the most generally employed insect wash is a petroleum emulsion made according to the following formula :—

1 part soap, 10 parts water, 20 parts petroleum ; the soap is dissolved in hot water and the petroleum slowly added to the hot solution with constant stirring. A creamy mass results, which for use is mixed with 15 parts of cold water. On the small scale this solution is distributed from a knapsack spray with a hand pump ; power sprayers conveyed in carts are also in use, but the writer believes their employment is confined to the fruit industry carried on over comparatively limited areas.

Extract of pyrethrum is a widely used insecticide, and is thus prepared[14]:—

Genuine Persian or Dalmatian insect powder, 100 grms.; raw spirit, 200–250 grms.; 80–100 grms. ammonia; allow to stand for two days. Dilute with two litres of water and allow to stand exposed to the sun for a few more days; filter through a cloth, squeezing out the residuum well. The dark brown liquor is extract of pyrethrum. Use 25 grms. of this and 25 grms. of soft soap per litre in aqueous solution.

6. *Flooding.*—The flooding of fields has been proposed as a means of destroying the larvae of those insects that are subterraneous in their habits.

7. *Destruction of breeding Places.*—Many of the parasites of the cane utilize trash, dead cane, &c., as breeding places, and following this the destruction of all refuse likely to harbour insects has been advised ; agriculturally this process leads to a loss of nitrogen, and Perkins has observed that the burning of trash, &c., may at times be ill-advised, as the leaf hopper is able to escape by flight, a faculty not possessed by all its parasites.

8. *Quarantine of imported Plant Material.*—It is certain that many of the serious epidemics of insects are due to their accidental importation unaccompanied by the natural enemies that keep them in check in their original habitat. Instances of these introductions are numerous. The 'Borer' was thus introduced into Mauritius in 1848 [15] in a consignment of cane received from Ceylon. Orders were given to destroy the cargo, but it is supposed that some ill-advised person secretly removed and planted a few tops. The introduction of canes from abroad also accounts for the Weevil Borer and Leaf Hopper in the Hawaiian Islands. It is of great interest to note that evidence exists that the borer of these islands was introduced from Otaheite along with the original Lahaina cane (*cf. Chapter IV.*); it was on the "Pioneer" estate at Lahaina that it was first noted a year or two after the introduction of the cane there. Another boring pest of the cane, *Sesamia nonagrioides*, originally a North African species, has now become widely distributed over the tropics.

When the immense damage done by insects is recollected (in the Hawaiian Islands alone the leaf hopper in one year destroyed cane equal to not less than 60,000 tons of sugar), any expenditure on a proper system of quarantine can only be regarded as a rational policy of insurance. Such a system is now established in the Hawaiian Islands.

9. *Infection with Disease.*—A number of years ago it was proposed to destroy rats by means of bait infected with cultures of the organism *Septicaemia muris;* the first essays in this direction were not attended with success, but more lately favourable reports have been received of the efficacy of 'Dansyz virus' as a muricide; the use of this has, of course, been chiefly developed in connection with the prophylaxis of plague.

A number of micro-organisms are parasitic upon insects; thus the death of the weevil borer has been observed as due to the mould *Penicillium glaucum ;* a fungus, *Isaria barberi*, is also known as parasitic upon the caterpillar of the West Indian moth borer, and a species of *Botrytis* upon the caterpillars of the moth *Psalis securus* in Java. The help afforded by these fungi does not appear to be very great. The destruction, however, of the scale louse *Aleyrodes longicornis* by a fungus *Ascherontia aleyrodis* in Florida has been noted by Webber[16] apparently acting with good effect.

10. *Encouragement of natural Enemies.*—The increase of many pests is often traceable to a decrease in the number of their enemies; an example of this is the great increase of the mole cricket in Porto Rico in 1876[9] after the destruction of the avian population of that island in a hurricane. Amongst the insectivorous animals which may be classed as friends of the cane are birds, lizards, newts, toads, ladybirds and spiders. In this connection Dr. Perkins informs the writer that the destruction of the 'grass army worm' in the Hawaiian Islands is due largely to the mynah bird, an introduced species.

11. *Parasitization.*—If the checks on insect multiplication were removed agriculture would be impossible. To the great majority of insects are attached

one or more parasites, and it is due to the absence of the parasite that the sudden outbreaks of insect damage are due. The control of insect damage is to be obtained by the introduction, breeding and distribution of approved parasites. A striking example of this method is afforded by the work of Koebele, Perkins, and their associates in the control of the leaf hopper pest in the Hawaiian Islands. This insect was introduced unaccompanied by the parasites which in other places kept its development in check ; expeditions were sent to Fiji, Queensland and elsewhere, parasites were obtained, bred and distributed, and the leaf hopper was in a few years placed under control ; this achievement may well be considered as a classic in economic entomology. The parasites found to be the most effective were extremely minute hymenoptera, belonging to the *Calcididae*, of which *Paranagrus optabilis*, **P.** *perforator* and *Anagrus frequens* were the most valuable. These parasites lay their eggs on the eggs of the leaf hopper, and this form of parasitization is considered the most effective.

Very often cane pests are kept in check by naturally occurring parasites ; thus a species of *Chrysopa*, belonging to the neuroptera, controls the ' spittle fly,' *Delphax saccharivora*, in the West Indies. In Java, the detailed studies of Zehntner, Van Deventer and others have brought to light many parasites ; the ' moth borers ' are thus controlled there chiefly through the agency of two minute chalcid hymenoptera, *Ceraphron beneficiens* and *Chaetosticha nana ;* other of the pests in Java (and doubtless elsewhere) are controlled by other minute hymenopterous insects which may be well considered as amongst the most beneficial of their kind. In *Figs. 58* and *59** are given, after Van Deventer, a drawing of *Ceraphron beneficiens*, and the eggs of the ' Borer,' *Diatræa striatalis*, parasitized by this insect.

Amongst other beneficial insects may be mentioned various ' ladybirds ' (*Coccinellidæ*) to which the control of aphis and other 'plant lice' is largely due.

It may also be mentioned that the planting of certain plants, *e.g.* Pigeon Pea (*Cajanus indicus*), Bonavist Bean (*Dolichos lablab*), near to cane fields has been stated to attract the hymenopterous insects parasitic on many cane enemies.

The question of pest control by parasites and predators is, however, a most complicated one, and includes many factors grouped together in the term ' *struggle for existence*.' Thus there may be a major pest of the cane, A, and a minor pest, B, which is also predatory on A. Amongst these may be intro- duced a third form of life, C, parasitic on A, which in its turn is parasitized by D, which also includes B among its hosts. It is only by the careful study of the life history of the pests and of their parasites, and by taking into account all conditions, that it can be determined if the introduction of such and such a form of life is advisable ; the ill considered disturbance of the natural balance, as instanced by the results of the introduction of the mongoose into Jamaica, is unreservedly to be condemned.

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* See *Frontispiece.*

For a detailed study of the control of insect pest by insect parasite reference may be made to the detailed account of the leaf hopper in the entomological bulletins of the Hawaiian Sugar Planters' Association.

Froggat[17] however, has very severely criticised the pest control work of Koebele and Perkins, and is inclined to attribute the diminution of the leaf hopper to the burning of trash, (a custom which had been in vogue for a generation previous to the appearance of the hopper), and which Perkins indeed does not advise since the hopper can escape by flight, whilst the parasites are unable to do so. A change in the variety of cane planted is also given by Froggat as tending to have controlled the hopper, but although on some plantations hard rinded varieties were hurriedly planted during the first period of the epidemic, this alone had little effect, and plantations which made no change obtained an effective control by means of parasitization.

On the other hand, Silvestri,[18] who also studied the conditions locally, writes in the highest terms of the work of Koebele and Perkins, and considers that there is no doubt of the economic success of insect pest control through the agency of their parasites.

Insect Epidemics.—In the preceding pages reference has been made to several historic insect epidemics; in many of these there is strong evidence that the epidemic was due to external introductions and these may then be classed as instances of the *disturbance of the natural balance.* In one instance, at least, an epidemic was probably due to wilful neglect of warning and to disobedience of State orders. The losses suffered by Mauritian planters, about 1850, from the borer should be sufficient to warrant the introduction of new varieties of cane only under a well advised system of inspection and quarantine

Insect epidemics may however arise from uncontrollable causes, as instanced by the present (1910) serious aspect of the spread of the Giant Borer (*Castnia licus*) in British Guiana[19]. This insect was first noticed as casually attacking cane about 1901 on the East Coast of Demerara; in 1904, it was reported as doing great damage to cane at ' Enmore ' in that district; previously its food habits were only connected with the roots of an orchid growing near the Upper Orinoco. As this insect is known from Central America to the Amazon, it probably was not a recent introduction, but suddenly for obscure reasons developed the faculty of feeding on the cane.

Although the presence of an active State entomologist would not have influenced the development of the habits of this insect, yet the reporting to such an official of the first observed damage in 1901 would have allowed him time to study its life history, to have warned planters of the imminent danger, and to have devised means for its control.

In any community dependent on agriculture for its prosperity, a department of economic entomology is necessary; the losses due to preventable epidemics would pay the expenses many times over; whether the officials of such a body should be the servants of the State or employés of a private

association is debatable; means for the enforcement of its recommendations are necessary however, lest the carelessness of a few individuals destroy the whole object of its existence.

Fungus Diseases.[*]—The diseases due to fungi are numerous and collectively cause annual losses of enormous sums; they have been studied amongst others by Krüger, Went and Wakker in Java, by Howard and Lewton-Brain in the West Indies, by Cobb in Queensland, by Cobb and Lewton-Brain in Hawaii, by Barber and Butler in India, and at Kew by Massée.

The most prominent diseases are the Sereh of Java, the Rood Snod of Java, which is cosmopolitan and is best expressed in English as Red Rot of the Stem, the Rind Fungus of West Indies, the etiology of which is still imperfect, the Black Smut and Top Rot, the cosmopolitan 'pine-apple disease,' Cobb's Gumming disease, and various so-called root diseases, most of which appear to be due to basidiomycetous fungi. In what follows an attempt is made to collate some of the more important points.

Leaf Diseases.—The leaf diseases of the cane are numerous and wide-spread, but none are very dangerous; they have been chiefly studied in Java and more lately by Butler in India; comparatively little attention has been paid to them elsewhere.

1. *Djamoer oepas.*—Large brown patches occur on the leaf and sheath, caused by a silvery mycelium found on the surface, the haustoria of which penetrate into the leaf, especially on the underside, and on the interior of the sheath. Later, small bodies (*sclerotia*), first white, then yellow, and finally brown, are observed on the dead portions of the leaf; these spots are the size of a grain of mustard; the leaves attacked soon wither and die, but the damage is unimportant.

2. *Yellow Spot Disease.*[20] *Cercospora kopkei.* Krüger.—This disease occurs as dirty yellow spots, often meeting to form one irregular blotch,

the centre of which becomes red. A brown mycelium is found on the leaf, the branches of which, sometimes isolated, sometimes united in bundles, carry colourless spores; the appearance of the underside of the leaf is as if covered with a white dust. The damage is not great.

× 270

Fig. 60.

The technical description of this fungus is:—*Cercospora kopkei. Maculis amphigenus, sinuosis confluentibus purpureo brunneis infra palidoribus, margine concolori ; hyphis plerumque hypophyllis fasicudatis, septatis apice nodulosis, denticulatisque fumoso bruneis 40 − 50 × 7 conidiis fusoideis suberectis 20 − 50 × 5 − 8 medie 40 × 6 utrinque obtusiaculis 3 − 4 septatis non constrictis passum guttulates subhyalinis.* Various forms of the spores of this disease are shown in *Fig. 60.*

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[*] See note in *Appendix.*

3. *Leaf Spot Disease.* *Pestalozzia fusescens var. sacchari.* Wakker.—
This fungus forms irregular spots on the leaves with a withered centre and
brown border; it is a rare and unimportant disease.

4. *Cane Rust.*[21] *Uredo kühnii.* Wakker and Went.—Narrow orange
coloured stripes appear on the leaf, especially on the underside, and from these
stripes an orange coloured rust can be
scraped; this serves to distinguish
the fungus from other leaf fungi of the
cane. The rust is composed of the
spores of the fungus. Krüger des-
cribes this fungus as *Uromyces kühnii.*
In Java the disease is everywhere
present in damp districts, but the
damage done is small. The technical
description is:—*Uredo kühnii. Soris
uredo sporiferis hypophyllis linearibus;
uredo-sporis e globoso ellipsoidiis v*

FIG. 61.

*pyriformibus, contentu aurantiaco exosporio copiose aculeato hyalino 18—34·5 ×
28·5 − 57·5 ; pedicellio hyalino clavato suffultis.* Various forms (after Krüger)
of the spores of this fungus are shown in *Fig. 61.*
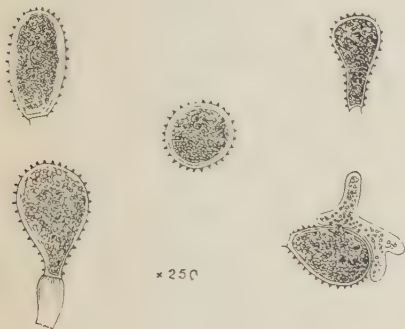
5. *Eye Spot Disease.*[22] *Cercospora sacchari.* Van Breda de Haan.—
The presence of the disease is indicated by small red dots, which grow into
long elliptical dark red spots, with
a light yellow margin; at a later
stage the centre becomes a dull dead
yellow, surrounded by a dark red
area, and this is circumscribed by a
bright yellow border; the elongated
elliptical shape of the spots, which
may grow up to 1½ to 2 inches in
length, is retained; the appearance
of the spots is not dissimilar to the
eye on a peacock's wing. With a
pocket lens hairs (*conidiospores*) may

FIG. 62.

be seen growing from the leaf. The disease has been observed in Java and
in Hawaii; in Java it does not appear on Cheribon cane or in mountain
plantations, and in Hawaii it only makes much progress in wet weather;
varieties differ much in susceptibility. The technical description of this
fungus is:—*Cercospora sacchari. Hab. in foliis, quæ maculantur, sacchari
officinarum. Hyphæ pluriseptatæ, bruneæ, 120—60 ; conidia 60 − 80×9 − 12 ;
vermicularia 5 − 8 septata brunea.* Forms of the spores of this fungus (after
Cobb) are shown in *Fig. 62.*
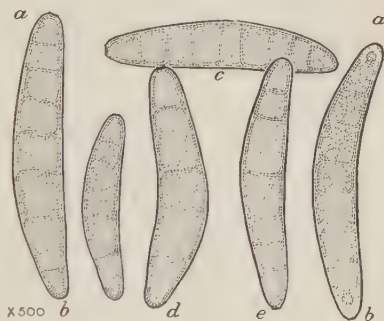
6. *Ring Spot Disease.*[23] *Leptosphæria sacchari.* Van Breda de Haan.—The appearance of a leaf of the cane attacked by this disease is so similar to that caused by eye spot disease that confusion is easily possible. The differences are that in Ring Spot the spots are seldom more than half an inch long, and are nearly as broad as long. The bright yellow margin observed in eye spot is absent, and the centre of the spot is a dull greyish white. The conidia are formed chiefly on the under surface of the leaf; they are three-celled, the central cell being larger than the outer ones, the whole spore forming an obtuse-angled body; at a later stage perithecia appear on the leaf as small black spots. Each ascus contains eight four-celled bobbin-like spores. The spores of this fungus are shown (after Cobb) in *Fig. 63*.

FIG. 63.

7. *Red Spot Disease.*[24] *Eriosphæria* (Went.) *Coleroa* (Van Breda de Haan.) *Venturia* (Saccardo) *sacchari.*—This organism forms dark red spots on the leaf, generally roughly circular, and about 1 cm. in diameter. The connection between the disease and the fungus has not been proved by infection experiments. In Hawaii, it is said, spots exactly similar to those described have been noted without any indication of the *Erisphæria* being present. The technical description of this fungus is:—*Venturia sacchari. Hab. in foliis sacc. offic. Perillecia 70—80 diam., asci 25 long; octospori, sporidia 11×16.*

8. *Black Spot of the Leaf Base.*[25]—A blackening of the leaf base has been observed in Java to be due to an organism, *Cercospora acerosum.* The spores are bobbin-shaped, from 2—3·5 microns wide and from 10—50 microns long; they contain from one to as many as seven cells. These spores (after Dickoff and Hein) are shown in *Fig. 64*.
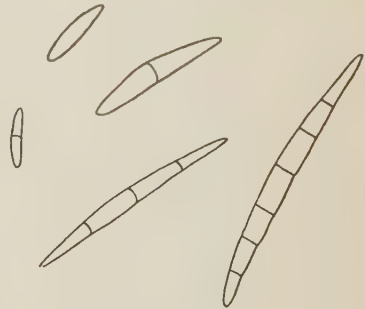
9. *Leaf Splitting Disease.*[26]—This disease, which is perhaps confined to one district in Hawaii, is characterized by a number of yellow stripes appearing in the leaf, which afterwards splits and withers. Cobb considered this disease due to an organism, *Mycosphærella striatiformans,* but did not prove the connection by inoculation experiments. Similar, and perhaps, identical diseases are known in Fiji and the Argentine.

FIG. 64.

140

A disease similarly characterized was described in 1849 by Bojer[27] in Mauritius, who attributed it to electrical influences in the atmosphere.

10. *Yellow Stripe Disease.*[28] (*Gele Strepen Ziekte.*)—This is a leaf disease often referred to in the Java literature, and as yet imperfectly diagnosed. Some references show points of similarity with the ' leaf splitting' disease of Hawaii.

11. *Brown Leaf Spot.*[29] *Cercospora longipes.*—The disease due to this organism is described by Butler as prevalent in North and South Behar; narrow oval spots about ⅛ inch long and of a reddish colour are the first signs of the disease; as the spots increase in size a brown centre becomes evident, and at one stage of the disease three concentric rings, brown, red and yellow, are seen; eventually the spot become a broad oval deep brown ring, with a straw coloured centre. The rings are usually from a quarter to a third of an inch long by an eighth of an inch or more in breadth. The technical description of this fungus is :— *Cercospora longipes. Maculis elongatis, amphygenis, saepe confluentibus, primo sanguineis, orescendo stramineis, brunneo-cinctis ; hyphis in caespitulos gregarios collectis, plerumque hypophyllis flexuosis, brunneis, sursum geniculatis vel denticulatis, 100—200 × 4 conidiis obclavatis sursum attenuatis, rectis vel curvatis, 4—6 septatis, 40—80×5 hyalinis.* In *Fig. 65* are shown (after Butler) spores of this fungus.

FIG. 65.   FIG. 66.

Diseases of the Leaf Sheath.

1. *Eye Spot of the Leaf Sheath.*[30] *Cercospora vaginæ.* Krüger.—This disease is characterized by a brick red spot appearing on the leaf sheath; this red colouration does not spread over the leaf sheath; the centre of this spot becomes eventually black. The disease is due to the organism *Cercospora vaginæ*; Krüger gives the length of the spores as from 19·6—40 microns, with an average length of 25·2 microns, and the breadth as seven microns. In *Fig. 66* are shown (after Krüger) spores of this fungus.

2. *Red Rot of the Leaf Sheath.*[31]—The organism causing this disease is imperfectly known; the disease is characterized by the leaf sheath becoming red, the red colouration spreading all over the sheath, and shading off into an orange colouration. The disease passes from the leaf sheath to the stem, attacking the soft parts near the nodes; at a late period of development the

infected parts are covered with an abundant mucus mycelium, and eventually a large number of sclerotia the size of a pin's head are produced; these are first white, and finally become yellow and brown. The diseased parts have a smell of mushrooms. It is young cane that is most often attacked, and in the case of tops the germination of the eyes may be prevented.

3. *Acid Rot of the Leaf Sheath.*[32]—A disease much resembling the Red Rot, and also incompletely diagnosed. It is distinguished by the lighter red colour of the infected parts, by the larger sized orange sclerotia, and by the odour of apples. The disease does not readily pass to the stem, and then only attacks the young internodes.
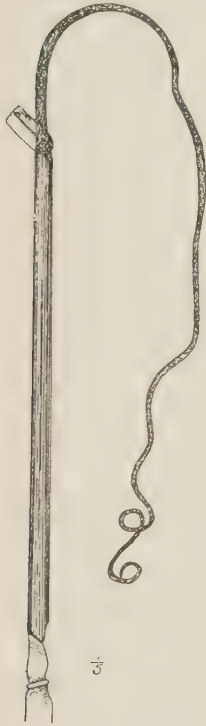
Diseases of the Stem.

1. *Black Smut.*[33] *Ustilago sacchari.* Rabenhorst.— The organism which causes this disease is found in all affected parts. The part of the cane most liable to attack is the top of the young cane, which is turned into a black, whip-like substance, covered with a slimy foul-smelling material; the whole stool of cane is destroyed. The organism is found on grasses and on wild cane, the latter in Java having been noted as a source of infection. The disease occurs in Java, Natal, Queensland, and India, where Butler has observed the possibility of the disease appearing from the use of infected tops; he does not consider it a dangerous disease, but the writer has seen great damage caused in Mauritius. In one case a seven-acre field was absolutely destroyed. Butler also observes that the fungus has a predilection for those varieties of cane approaching wild cane. The technical description of this fungus is:—*Soris atris: Sporis globosis subangulatis, 8–18 olivaceo-bruneis, vel rufescentibus, episporio crasso levi instructis.* In *Fig. 67* is shown the whip-like appearance of the cane attacked by this disease, and in *Fig. 68* spores of the fungus.

FIG. 67.

2. *Donkelan-ziekte.*[34] *Marasmius sacchari.* Wakker.—This is a disease attacking the foot of the cane, and, so far as regards Java, appearing chiefly in nurseries. The disease is characterized by the withering of the leaves of the young shoots, and by the non-development of the buds. The cane plants contain in the interior a mycelium which also occurs as large white flakes on the surface of the cane. The fungus has been studied in the West

x 270.
FIG. 68.

Indies by Howard and Lewton-Brain. Here adult cane is usually affected, particularly ratoons; the roots are attacked, and the cane dies from want of water. After rains the toadstool is often found growing at the base of the cane. Wakker's technical description of this fungus is *Gregoria*

Nat Size

FIG. 69.

vel basi fasci-culata, diversa, carnoso-membranacea persistentes; pileus albus late-campanulatus dein sordide albus, planus vel cupuliformis, 15 mm. diam.; lamellae albae simplices vel bifurcatae. Stipes centralis albus, long. 15 mm. apice tubiforme base villosa. Hyphae albae. Sporidia hyalina, continua, irregulariter-oblonga utrinque attenuata 16 — 20 × 4 — 5. Habitat in caulibus vivis. This organism or one closely related also occurs in Hawaii, and has been provisionally named *M. sacchari*, var. *Hawaiiensis*. A marasmius is also, according to Fulton,[35] parasitic on cane in Louisiana, and is identified as *M. plicatus*, which has been observed as a saprophyte in Java. In *Fig. 69* is shown the toadstool of this fungus as appearing in Hawaii, and in *Fig. 70* the spores, both after Cobb.

3. *Top Rot* or *Pokka Bong.*—The etiology of this disease is considered uncertain by Went and Wakker. It has been connected with Cobb's Gumming Disease, but later researches, especially those of Erwin Smith,[36] indicate that these diseases, whilst somewhat similar in outward appearance, are totally distinct.

Three stages may be recognized in the disease. In the first the young leaves become yellow, wither and die, while the internodes, being unable to obtain food, remain short and stunted; in the second stage the young leaves that have opened roll up and die; in the third stage the vegetative point is changed to a slimy pulp, the remainder of the top being filled with a slimy substance possessing a foul smell similar to but distinct from that associated with the *Ustilago sacchari*. Later the eyes underneath the top shoot and may form almost a new top. Young plants a few months old are more often affected than mature cane, and continued rain is a predisposing cause. On an estate

FIG. 70.

with which the author was connected in Demerara, a rot, outwardly the same as the one in question, was very prevalent, and he made the following observations:—Older canes frequently suffered, but there was always previous insect damage of the top. In young canes of age from a few days (*i.e.*, when the eye was sprouting) to two or three months the apical leaf was frequently

seen to wilt; on applying a steady tension this could be pulled out entire, or in the case of a sprouting eye, the bud could be unravelled; at the base of the leaf a discoloured area was seen associated with a foul smell; by examining sprouting eyes which were just beginning to wilt, or even which were apparently healthy, all stages of the rot could be seen; in many cases there was evidence of previous damage by an undetermined insect, the larva of which (a footless grub, about $\frac{3}{16}$ inch long) was present; *but frequently there was no sign of insect damage.* This disease was certainly causing no inconsiderable harm.

4. *The Gumming Disease. Pseudomonas vascularum.* Cobb. This disease, which has been incorrectly associated with Top Rot, was originally described by Cobb in Queensland. It is characterized by the exudation of drops of gum from a cut or punctured surface, as shown in *Fig. 71.*

FIG. 71.

The top of the cane also becomes charged with a putrid offensive slime. Cobb connected the disease with the presence of a micro-organism which he called *Bacillus vascularum*, but did not make the complete bacteriological proof of the connection of this organism with the disease. This has been done later by Erwin Smith,[36] who has definitely proved the connection between gumming and Cobb's organism. An important point in Erwin Smith's research is that he shows that the 'common purple cane' and D 74 are much less susceptible than the 'common green cane,' and connects this with the less acidity of the 'common green cane.' Greig Smith[38] also proved that the bacillus grown in pure culture produced the characteristic gum found in the vessels of diseased cane. He also noted the resistance of variety to the disease.

Erwin Smith thus describes the appearance of the organism:—

The organism appears as an actively motile, short rod, and when stained and imbedded in balsam has an average measurement of 0·4 : 1 micromilli-metres. Carbol violet followed by dilute alcohol produces the best films; fuchsin stains the gum, which usually adheres more or less to the cells; the blues stain but feebly. By using the night-blue method with the scanty growth obtained on ordinary agar the flagella can be easily stained. They are single and terminal. The bacteria are not coloured by the Gram method of staining. Spores were not obtained and are probably never formed.

FIG. 16.
SALANGORE.

PLATE IX

Sereh.—This disease was first recognised as such in 1882 in Java where it has done very great harm. In the typical form of ' sereh ' the stool of cane consists of a number of short stalks with very short joints; the buds, especially those below, sprout, whereby results a bundle of short stems hidden in a mass of leaves. The whole stool bears a resemblance to lemon grass (*Andropogon schoenanthus*) the Javanese term for which is ' *sereh.*' In a second type one or two stalks may grow to a fair size with very short joints in the upper part; above all is a fan-shaped leaf crown; many of the eyes, especially those below, sprout and form small branches. Benecke [39] has given the following symptoms of this disease :—

1. A low, shrubby growth, often only from 3–4 decimetres.
2. A fan-shaped arrangement of the leaves arising from a shortening of the internodes.
3. The internodes are only from $\frac{1}{3}$ to $\frac{2}{3}$ inch long.
4. The nodes are tinted red.
5. Numerous aerial roots are formed.
6. The fibrovascular bundles are tinted red.
7. Subterraneous outbranchings form.
8. The sheath and root buds turn vermilion.
9. In some cases there is no formation of wax on the stem.
10. The growing part of the stalk is frequently dyed red.
11. The leaf-sheath and the stalk stick together.
12. There is an accumulation of secondary organisms.

The presence of gum in ' *sereh* ' cane is a point about which much has been written; the major portion of opinion seems to be that the presence of gum is a consequence of, and not directly connected with, the disease; if the gum is of bacterial origin the growth of the bacteria might only take place in canes already weakened by disease.

A red colouration of the fibrovascular bundles is a characteristic of ' sereh '; this colouration is most pronounced in the node, but often appears in the internode in the form of a red stripe; this appearance is quite distinct from the red patch with white centre characteristic of the ' *red rot of the stem.*'

A red string of the sugar cane associated with the presence of gum has also been described by Grieg Smith[40]; this he ascribes to the association of an unidentified ascomycete with a slime producing bacillus, which he names *B. pseudarabinus.*

The immense amount of work that has been done on Sereh has quite failed to elucidate the cause of the disease; opinion is divided in ascribing the cause to physiological and to pathological influences; amongst the first, bad drainage, injudicious manuring, late planting, excessive ratoonage, an insufficiency of silica in the soil, and *degenerescence* have been suggested.

145

As regard parasites, Treub[41] ascribed the disease to the attacks of a nematode worm to which he gave the name *Heterodera javanica*. Coinciding with the attacks of this worm he observed the presence of a fungus of the genus *Pythium*. This worm penetrated the bark of the root at places of accidental injury or at the growing point. After having arrived within the root the worm worked its way parallel to the central axis until it arrived at the point of growth of a lateral root. Soltwedel[42] also attributed the damage to attacks of a worm to which he gave the name *Tylenchus sacchari*, stating that the parasite passed its existence in the root which it destroyed. The length of the Tylenchus is given by Soltwedel as about ·7 mm. and its breadth as about ·03 mm.

The connection between nematode worms and Sereh is not now generally accepted.

Janse[43] ascribed the cause of Sereh to two organisms, *Bacillus sacchari, and Bacillus glangæ*, and stated that these organisms attack other plants besides the cane. He considered the seat of the disease lay in the reddened fibro-vascular bundles. The dependency of Sereh on these organisms is not now generally accepted.

Lastly, Went attributed Sereh to a combined leaf-sheath and root disease, caused by an organism *Hypocræa sacchari*, the description of which is as follows :—

Pulvinata dein depressa, carnosa, pallide fusca, stromatibus 2 — 4 mm. lat. 1 mm. crassis, sæpe læviter collascentibus, intus pallentibus vel albidis, pertheciis fuscis, ostiolis, vix prominulis 200 − 250 = 150 − 200, ascis linearibus breve pedicellatis 100 × 5, sporidiis monostichis 8, e cellulis duabus inæqualibus mox decedentibus compositis, cellula superiori globosa 4 diam., cellula inferiori cuboidea oblonga 6 × 4, fumose-olivaceis, conidiis. Verticillium sacchari.
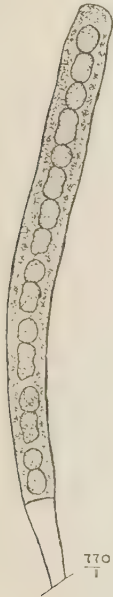
In *Fig. 72* is shown (after Went) an ascus of the Hypocræa, containing eight spores. Latterly the idea seems to be taking hold that Sereh was the manifestation of peculiar soil and cultural conditions, the various micro-organisms associated with it only becoming prominent after the health of the cane had become affected.

FIG. 72.

A point of great interest with this disease is the difference of opinion as to its infective nature ; the disease certainly spread from district to district in Java, but conversely healthy sticks planted in an affected field remained healthy. Whether infectious or not, the disease was found to be hereditary : that is to say, canes planted from sound healthy seed gave healthy canes, but tops derived from sereh struck canes became equally infected.

The localization of the disease to Java, or its presence elsewhere, is of great importance; in the literature references may be found to its appearance in Australia, Mauritius, and Réunion; the only *authoritative* statement I have come across is due to Went, who saw Black Java canes in Surinam with the symptoms of the disease. The writer himself has not infrequently in Mauritius and Demerara seen canes presenting the symptoms of sereh, including the red stripe; it is admitted that such symptoms may be present in sereh-free canes, and these symptoms appearing in other than sereh canes may account for the great diversity of opinion as to the cause of the disease.

6. *Red Rot of the Stem.*[44] *Colletotrichum falcatum.* Went.—The *Red Smut* has been carefully investigated by Went. He says that diseased plants do not show any outward sign of disease so long as they are not seriously affected. At a later stage the plant dies away, the leaves becoming prematurely withered and yellow. On cutting the cane longitudinally the joints are found to be affected, but two consecutive joints are seldom diseased. The disease shows itself in the shape of a red colouration in the interior of the joint, which is unequally distributed and darker in one place than another; peculiar white spots are also to be seen. This appearance serves to distinguish the disease from Sereh, which is marked by a red stripe. The rind is unaffected, and since the fibrovascular bundles are chiefly congregated near the rind, the leaves are still able to obtain their food.

In the white blotches a mould is always present, a few threads of mycelium being found in the red patches. In the vascular bundles brownish-black patches also occur, connected with which is a mycelium flourishing in the cells and walls of the bundles.

If a piece of diseased stem be allowed to dry, black streaks appear, due to stromata, from each of which spring a number of brownish-black straight hairs measuring from 100 μ to 200 μ in length and 4 μ wide. Among these hairs arise a number of sickle-shaped conidia, measuring 25 μ by 5 μ. If the diseased cane be kept in a damp place a white mycelium turning to grey appears, forming, in a few days, chlamydospores or resting spores. Went never obtained any form of spores other than conidia or chlamydospores. To the organism described above he gives the name *Colletotrichum falcatum*, and states that it is a wound parasite, only attacking canes already injured by insects. The organism has also a selective power for different varieties of cane. The complete description by Went of this is: *Colletotrichum falcatum. Setis nunc seriatis, nunc in pseudo-conceptaculum congregatis cuspidatis, 100−200×4, fulgineis, sursum pallidioribus, conidiis falcatis 25=4, hyalinis, ad basim setulorum, basidiis ovoideis 20×8, hyalinis vel fuscis, suffultis. Habitat in culmis vivis.* This organism is cosmopolitan. More recently the fungus has been studied by Lewton-Brain,[46] who has shown the existence of an enzyme secreted by the fungus, to which the loss of sugar is due.

In *Fig. 73* is shown from a photograph (after Lewton-Brain) canes attacked by this fungus, revealing the characteristic white spot in the centre of the red coloration, and in *Fig. 74* the spores of this fungus.

FIG. 73.

7. *Pine-apple Disease.*[45] *Thielaviopsis ethaceticus.** Went.—The *Ananas* or *Pine-apple* disease is, like the last-mentioned, a wound parasite, and its favourite place of attack is the exposed ends of cuttings for seed cane; fully grown cane is rarely affected. When a cutting is attacked, the interior at first becomes crimson red and then black, at the same time giving off a

* See note in *Appendix.*

pleasant odour reminiscent of pine-apples. A fungus, *Thielaviopsis ethaceticus*, was found by Went to be the cause of the disease. Cultures made from diseased

FIG. 74.
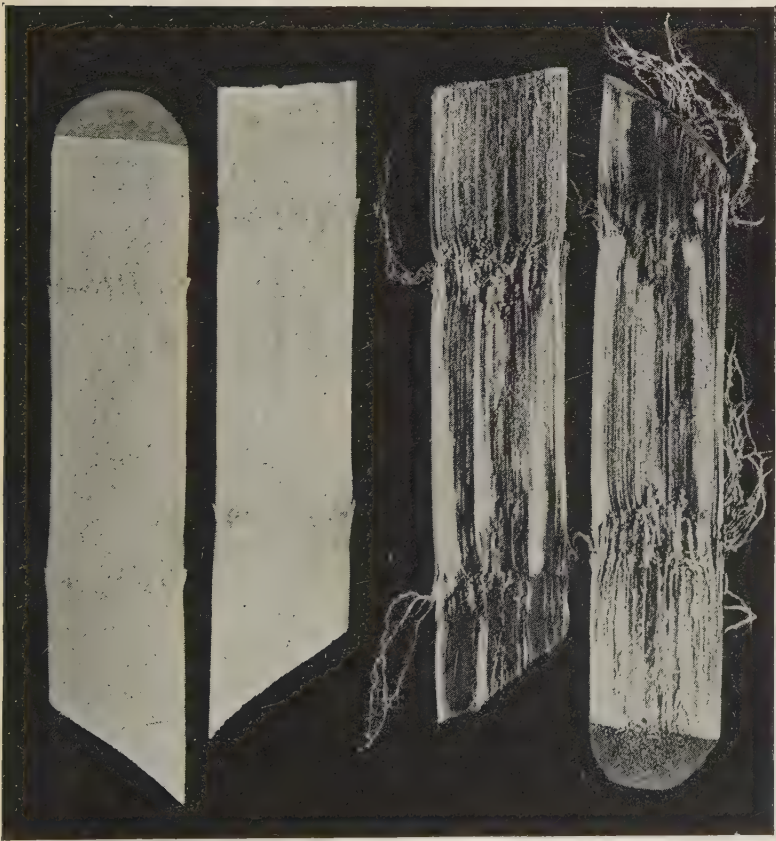
FIG. 75.

canes remain white for from twelve to twenty-four hours and then turn olive-green; this colour is due to macroconidia situated in the special cells at the ends of short branches of the mycelium. Microconidia are also formed in chains of

three or more. They are formed within the top of a hypha and are rect-angular and colourless. The complete description of this fungus is thus given by Went :—*Thielaviopsis. Hyphae steriles hyalinae vel pallide fuscae, septatae.*

Hyphae fertiles septatae non ramosae. Macroconidia ovata, fusca, catenulata, mox secedentia. Microconidia cylindracea vel bacillaria, hyalina, in interiore hypharum catemulatim generata et mox ex apice exsilientia. T. ethaceticus. Macroconidia 16 − 19 × 10 − 12, microconidia 10 − 15 = 3, 5 − 5, in interiore hypharum 100 − 200 μ long. Habitat in culmis, fructibus, foliis in insula Java.* This organism is cosmopolitan.

X 325

FIG. 76.

In *Fig. 75* are shown photographs of sound canes and of canes attacked by this fungus; in *Figs. 76* and *77* are shown the macro-and micro-spores.

8. *Cytospora sacchari.*[29] This organism has been observed by Butler, probably as a parasite of sugar cane in India ; canes attacked resemble those attacked by rind fungus, and it is stated by Butler to be pro-bably of only minor importance.

X 400

FIG. 77.

The technical description of this fungus is :—*Cytos-pora sacchari. Butler. Stromatibus verruciformibus seriatim ordinates, subcataneo-erumpentibus, plurilo-cularibus, nigris, osteolo elongato, singulo rariis, duobus praeditis ; sporulis minutissimis, cylindraceis, curvulis, utrinque obtusis ; 3·5 × 1·5 microns ; basidiis ramosis septatis, 12 − 18 microns. Hab. in culmis vaginisque sacchari officinarum India.*
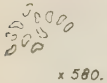
x 580.

FIG. 78.

In *Fig. 78* are shown (after Butler) the spores of this fungus, and in *Fig. 79* a part of the diseased stalk.

9. *Diplodia cacaoicola.*[48] P. Henn.—This organism, which is known chiefly as a disease of the cacao tree and pods, was observed by Howard in the West Indies to be also parasitic on the cane. The appearance of canes attacked by this organism is similar to that occurring in attacks of rind fungus. Affected canes have a shrunken appearance, and on the rind appear little pustules, from which hairs eventually exude ; in dry weather the hairs do not appear, the spores showing as a blackish crust on the outer surface of the cane. Howard succeeded in infecting canes with pure cul-tures of this organism, which has also been observed by Butler[29] on cane in India. The technical description of this organism

Natural Size

FIG. 79.

is :—*Pustulis prominalis nigris sporulis oblongis breniculeatis ; cirris nigris 12 × 5.*

In *Fig. 80* is shown (after Butler) a cane stem attacked by this fungus, and in *Fig. 81* the spores, also after Butler.

10. *Black Rot.*[9]. *Sphæronœma adiposum*. Butler.—An organism described under this name has been found by Butler in India, associated with *Thielaviopsis ethaceticus*, and Butler has succeeded in infecting healthy canes with this organism. His description of it is:—*Sphæronœma adiposum. Mycelio dense lanoso, atro ex hyphis brunneis, ramosis composito ; hyphis fertilis simplicibus, septatis, endoconidiis gerentibus ; endoconidiis polymorphis, cylindraceis, pyriformis vel globosis, aliis hyalinis vel brunneis, levibus, aliis fuscis verrucosis, 9 — 25 × 4·5 - 18 ; peritheciis globosis, pilosis, atris in collum erectum, rigidum, 2 — 6 m.m. × 50 microns, productis, ore sub-fimbriatis; sporidiis hyalinis, continuis, crasse lunulatis, utrinque acutis 6·5 × 3·5, muco adiposo obvolutis. Hab. in culmis sacchari officinarum, India. Fig. 82* shows a cutting infected with this fungus.
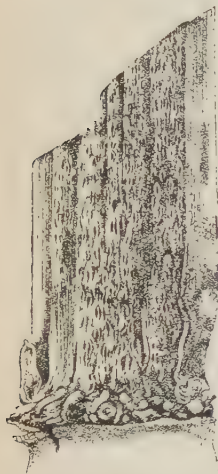
Natural Size

Fig. 80.

11. The *Maladie de la Gomme*, or Gumming Disease of Mauritius, has been described, as far as external appearance is concerned, by Bonâme. At first there is nothing abnormal in the appearance of the cane, but when the disease is fully established growth is stationary and the leaves turn yellow. If the stem is cut transversely, small masses of a yellow viscid matter appear on the cut surface, which dry and harden in the air. This gum is only found in the central fibrovascular bundles, and not in the sacchariferous cells. A gum, however, which is not yellow is also found round the knots and on the upper portion of the stem. In the final stage of the disease the extremity of the stem decays, the internal portion being filled with a grey viscid substance.

× 250

Fig. 81.

½ Natural Size

Natural Size

Fig. 82.

Diseased specimens of canes were forwarded to Prilleux and Delacroix,[49] who found on these canes an organism which they identified with *Coniothryrium melasporum*. This organism is the same as *Darluca melasporum*, found by Berkeley on Porto Rican canes, and is indentified by Howard with the *Diplodia cacaoicola*. The description of Bonâme agrees very closely with the appearance due to gumming as described by Cobb, and it is, of course, possible that the organism found by Prilleux and Delacroix was in a sense accidental, and not the cause of the disease.

12. *The Rind Fungus of the West Indies.*—By Rind Fungus in the West Indies is meant the black pustules and hyphae that appear on the rind of dead and damaged cane; it is thus described in the Kew Bulletin.[50] :—

" Canes infected with rind fungus are first noticed by dark red or brown patches in one or two joints toward the middle or base of the cane. This red patch having made its appearance rapidly spreads upwards and downwards, the infected area darkens in appearance, and is evidently rotten. Little black specks make their appearance between the joints, breaking from the inside to the surface."

Specimens of affected canes were examined by Massee, who considered the disease to be due to a sphaeriaceous fungus which he named *Trichosphaeria sacchari*, and he found macro-conidia in the interior, and micro-conidia on the wounded surface of the cane. Both these forms he obtained in flask cultures inoculated with stylo-spores.

Went thought that Massee's macro-and micro-conidia belonged to the fungus *T. ethaceticus*, and suggests the identity of a saprophyte of cane, known in Java as *Melanconium sacchari*, with the fungus producing the black pustules and Massee's sphaeriaceous fungus.

Howard,[5] in Barbados, investigated the connection between the *Tricosphaeria*, the *Melanconium* and the red smut (rot). His experiments and results may be briefly summarized :—

1. On canes attacked by rind fungus two organisms are always found— a *Melanconium* and the *Colletotrichum falcatum* of Went.

2. The *Melanconium* inoculated into living cane does not produce rind fungus, the damage being confined to the dead cells around the wound.

3. Canes infected with *Colletotrichum falcatum* reproduce all the features of rind fungus.

4. When canes are infected with *Colletotrichum falcatum* and afterwards with *Melanconium* spores, the latter grow.

5. The *Melanconium* always follows attacks of *Colletotrichum falcatum*, but does not itself attack living cane.

It is to be noted that Howard treats the popular term 'rind fungus' as synonymous with the Java 'rood snod.' This is unfortunate, as the 'red smut' is essentially a disease of the interior of the cane.

The *Melanconium* fungus is one that has been much studied, and other investigators do not treat it altogether as a harmless species. Cobb[37] describes it as 'cane spume,' identifying it with *Strumella sacchari*. He says, " I believe it is true that in most cases, if not all, this fungus requires the cane to be first in some way injured. Perhaps the frost so injures the arrow of the cane as to cause it to decay and die ; perhaps a borer makes its way into the cane, and thus breaks the rind ; or, again, perhaps the wind twists the stalk and cracks it, or the cane gets injured in any of the numerous possible ways ;

then this fungus stands ever ready to take advantage of the accident, and in a few weeks' time makes such an inroad as to send the whole cane well on its way to decay. . . . The amount of damage done by spume is difficult to estimate. There is no doubt that through its agency much cane, which though injured would be saleable, is soon rendered worthless."

As a result of further study in Hawaii, Cobb treats this fungus as strictly parasitic, and mentions that it is a frequent cause of the non-germination of cuttings used for seed.

Lewton-Brain[52] also treats the fungus as parasitic; his studies have indicated that the Melanconium is unable to penetrate the hard outer rind of the cane, but that when introduced through a wound, in a susceptible cane, it can enter the thin-walled cells, and bring about the death of the cane. He does not, however, regard it as markedly parasitic on varieties at present widely cultivated.

The literature of 'rind fungus' is very confused, but may be thus briefly summarized.

Howard treats rind disease as synonymous with the red smut of Java, caused by *Colletotrichum falcatum*.

Cobb and Lewton-Brain treat rind fungus as a disease caused by *Melanconium sacchari*, and Howard does not regard this organism as parasitic.

The planter, when speaking of rind fungus, refers to the appearance of black hairs growing out from a diseased cane; this appearance may be caused by the *Melanconium sacchari*, by *Diplodia cacaoicola*, or by *Cytospora sacchari*, and most often follows on attacks of other diseases.

Lewton-Brain calls the disease caused by *Colletotrichum falcatum* 'red rot of the stem,' thus distinguishing the disease from the red rot (rood rod) applied by Went and Wakker to a disease of the leaf sheath.

The organisms associated with the well-known appearance of rind fungus have been described under different names, and we have *Trichosphæria sacchari*— *Melanconium sacchari*—*Strumella sacchari* and *Darluca melasporum*—*Coniothryrium me'asporum*—*Diplodia cacaoicola*.

In the writer's opinion, the etiology of 'rind diseases' still remains obscure; those who have been unfortunate enough to have seen 'rind disease' at its worst in Demerara, the West Indies, or Mauritius will require much convincing that this appearance is not connected with an aggressive parasite; experiments with the *Melanconium* seem to prove that this form is not parasitic. On the other hand Howard has shown the parasitic nature of *Diplodia cacaoicola* on cane in the West Indies; an outbreak of 'rind disease' was observed by Harrison[53] in the experimental plots at Georgetown, British Guiana; on the affected canes Howard found the *Diplodia*; on Mauritius canes examined by Prilleux and Delacroix the same organism was found. All this seems to point to the *Diplodia* as being the aggressive parasite, and the cause of rind fungus, to the exclusion of the Melanconium.

Fig. 83 shows a cane attacked by the *Melanconium,* and *Fig. 84* shows the spores.
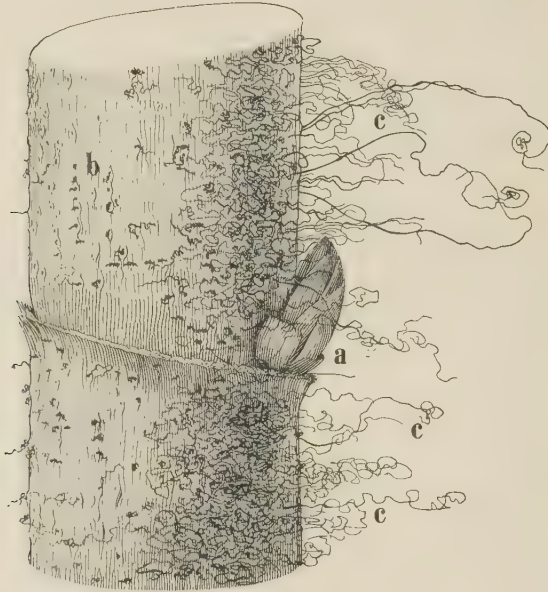
Fɪɢ. 83.

The Root Diseases of the West Indies.—This disease was shown by Howard to be due to the fungus *Marasmius sacchari ;* in Java this is considered as a disease of the stem, the basal part of which is attacked ; the roots of the cane also suffer so that the term 'root fungus' is justified ;

Fɪɢ. 84.

whereas in Java the disease is chiefly prevalent in nurseries, in the West Indies it is general and is particularly severe on ratoons. The disease is marked by the stunted appearance of the canes, by the dry leaf strap sticking to the basal end of the cane, by the presence of the mycelium which can be seen with the naked eye, and after rainfall by the appearance on the stalk of small fan-shaped toadstools.*

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* In Demerara the writer has seen canes die with all the outward signs of 'root disease'; the toadstools which appeared under favourable conditions of rainfall were not in any way like those of *Marasmius;* they were umbrella-shaped, with stipe 3-4 ins. long and with cap $\frac{1}{2}$-1 inch wide.

Root Fungi.—Under this term (Wortel Schimmel) there have been described in Java three fungi characterized by a growth of mycelium underground associated with the cane roots; the first of these was described by Treub as a *Pythium*, and considered by him as a cause of Sereh; later work by Wakker did not confirm this identification or connection. Wakker[51] further described two root fungi— *Cladosporium javanicum* and *Allantospora radicola*— as frequently occurring in cane fields but does not regard them as parasitic. Of similar habit is the *Ithyphallus coralloides* stated by Cobb to be the cause of a root disease in Hawaii; later work has not confirmed Cobb's views on the parasitic nature of this fungus, though some evidence exists that the underground mycelial strands interfere to some extent with the development of the cane roots. In the Hawaiian islands it is a matter of common knowledge that the *Ithyphallus* is often abundant on the most productive fields.

The Control of Fungus Diseases.

1. *Use of healthy, selected, disease-free seed for planting.*—This can be effected by careful selection, or by growing seed cane in nurseries remote from infected areas, or by using for seed cane from that part of a plantation which is observed to be the least disease affected, and rigidly rejecting for seed purposes any cane from parts of the plantation that are known to be infected with disease. The presence of red fibre is, according to Cobb, a sure sign that the cane is not disease free.

2. *Use of fungicide washes on the seed.*—The exposed ends of cane cuttings form a most convenient point of entry for fungus spores, particularly the *Thielaviopsis ethaceticus*, and it is this organism that is largely responsible for the non-germination of cuttings and the consequent expenses of ' supplying.' It has been shown by the experiments of Howard in Barbados, of Cobb in Hawaii, and of others, that soaking the cuttings in Bordeaux mixture preparatory to planting is a very efficient prophylaxis.

Bordeaux mixture is prepared as under :—

Dissolve 6 lbs. crystallized copper sulphate in 25 gallons of water.
Slake 4 lbs. of quick lime in 25 gallons of water.

Gradually add the lime water to the copper solution, with constant stirring ; when completely added, test the mixture by immersing in it for a few seconds a bright steel blade ; this should not become coated with a red layer of metallic copper ; but if the blade becomes coated more lime must be added.

The time during which the cuttings should be left to soak is half an hour.

In addition to soaking in Bordeaux mixture, the protection of the cut ends with tar has been proposed.

3. *Isolation of diseased areas and patches*, and destruction of fungus in these areas by heavy dressings of quicklime. This was recommended by Howard, Lewton-Brain, and Cobb, in connection with the various root fungi.

4. The adoption of all means likely to result in a diminution of flies is also recommended by Cobb, as he has shown how these insects are responsible

for the distribution of the spores of the *Ithyphallus coralloides*. The dissemination of typhoid, cholera, and dysentery by means of flies is now well recognized ; in these cases the flies visit human excreta, and carry the causal organisms to unscreened food and drink.

5. *Destruction of dead cane,* and of trash, as such material forms a habitat for certain organisms parasitic on living cane.

6. *Rotation of crops.*—The peculiar proneness of the cane to disease lies perhaps in the wide-spread practice of growing it continuously on the same areas; similar observations with regard to wheat grown continuously at Rothamsted have been quoted in *Chapter VI.* It is, perhaps, the various forms of ' root disease' which are most helped by this system. If other crops not susceptible to the fungi attacking cane were grown in rotation, the fungus would be starved, and would tend to disappear; as it is, the fungi have often a continuous habitat, and the soil becomes infested. Similarly lack of hygiene may lead to houses and districts becoming infected with pathogenic organisms.

7. *Selection of immune varieties.*— The work of Experiment Stations has been largely directed to this end ; and already seed varieties are grown on the large scale where, owing to the prevalence of disease, older varieties such as the Bourbon and White Transparent quite failed. An interesting point in connection with immunity is Erwin Smith's failure to infect the cane D 74. with the *Pseudomonas vascularum* (Cobb) to which 'gumming' is due. The Yellow Caledonia, or White Tanna, in Hawaii is also to be noted as a disease-resistant variety. In Java, the Sereh disease was, and is, controlled almost entirely by the selection of immune varieties.

In certain cases immunity may be connected with hardness of rind.

8. *Avoid all processes,* such as high trashing, that tend to injure or to expose the softer parts of the cane.

9. *Inspect and disinfect* all canes received from foreign countries. This process of quarantine can also be extended to a self-contained cane-growing district in some areas of which disease is known to be more prevalent than in others.

The Connection between Pests and Diseases.—When ' rind fungus ' was prominent in the West Indies in the nineties, great attention was paid to the possible sequence of disease on insect damage. This view has now become generally accepted ; to many diseases the hard outer rind of the cane acts as a partial barrier.

Disease Epidemics.—The history of the cane abounds with instances of sudden and destructive disease epidemics. In Réunion, during the years 1845-1851 a yellow cane—*qui n'était autre que la véritable Otaheite*[55]—was so attacked that it was necessary to entirely replace it with other canes ; this epidemic spread to or appeared simultaneously in Mauritius, and is the one to which Darwin refers in his *Variation of Animals and Plants under Domestication*, mentioning the substitution of a red cane (probably the Belouguet or Black Cheribon) for a white cane (probably Otaheite). This

disease, which at this time it is hopeless to attempt to identify, was characterized by a 'cork-screwing' (*tire-bouchonnage*) of the top, a 'yellowing off' and drying up ; the authority quoted above states that it is on record that the canes showed signs of *degenerescence* for fifteen years previous to the epidemic.* About 1865, the Louzier cane (*cf. Chapter IV.*) originated *per saltum* in Mauritius and there is evidence that this cane is the Otaheite, or staple cane of these islands, previous to the epidemic of the forties ; for a generation this cane remained the standard cane of Mauritius, and again in the nineties it suffered from a *maladie*. This disease has been discussed above. Here then exists a case of a cane twice forming the standard in a space of fifty years, and twice being almost exterminated by disease ; in the second epidemic relief was obtained by the planting of the Tanna canes.

Other disease epidemics are known ; in Madeira and Natal the Uba cane has replaced one which had become diseased ; in Australia the 'gumming' disease has assumed epidemic form ; the *Rind* fungus (the etiology of which is still not altogether satisfactory) of the nineties in the West Indies, and the *Sereh* disease of Java, so ably controlled by the plant-breeding work of Kobus and others, are well known instances. Though these epidemics are due to micro-organisms, yet the action of these is accentuated by, and perhaps may be initially caused by, negligence of plant hygiene. Quite recently Harrison[56] has struck a warning note when he writes:—"I have personally never favoured the readiness so apparent of late years to refer almost every instance of decreased yield in cultivated plants to the noxious action of microbes or fungi. It appears to me that for a long time back we have in the tropics rather neglected what I may call the physical and chemical hygiene of our cultivated soils, and have not paid sufficient attention to the soil-conditions which may have materially reduced the naturally resistant powers of plants to the attacks of bacteria and fungi. . . . . . And further, I think that the susceptibility of certain kinds of plants, for instance, the Bourbon cane, to injury by drought and fungus attacks is due in part at least to the defective conditions of soil hygiene under which, in places, they are now cultivated."

REFERENCES IN CHAPTER IX.

1. *Das Zuckerrohr.*
2. *De dierlijke vijanden van het suikerriet.*
3. *W. I. B.*, I., 327.
4. *Agric. Jour. of India*, April, 1908.
5. *Agric. Gaz.*, N.S.W., 1893, 373.
6. *S. C.*, 44–51.
7. *W. I. B.*, IV., 37.
8. *H. P. M.*, Nov., 1900.
9. *Porto Rico Agric. Exp. St.*, Bull. 2.

*May not this degenerescence have been due to the gradual infection of both seed and soil due to the use of infected tops ?

10. *S. C.*, 255.
11. *S. C.*, 146.
12. *Bull.* 6, *Path. H.S.P.A.*
13. *The Sugar Industry of the United Provinces of Agra and Oude.*
14. *S. C.*, 303.
15. *S. C.*, 44.
16. *U.S.D.A., Bull.* 13, *Div. of Plant. Path.*
17. *Official report on Fruit-Fly and other Pests in various Countries, N.S.W.*
18. *Hawaiian Forester and Agriculturist*, **VI.**, 287.
19. *U.S.D.A. Bull.* 54, *Div. of Entomology.*
20. *Medeelingen v.h. Proef Station*, **West Java**, 1890, 113.
21. *Loc. cit.*, 20, XIII.
22. *Loc. cit.*, 20, XVI.
23. *Loc. cit.*, 20, 1893, 25.
24. *Loc. cit.*, 20, 1893, 22.
25. *Arch.*, IX., 1015.
26. *Bull.* 5, *Path. H.S.P.A.*
27. *Trans. Roy. Soc. Arts and Sc., Mauritius*, 1849.
28. *Arch.*, I., 216.
29. *Mem. Dept. Agric., India Bot. Ser.*, I., 3.
30. *Loc. cit.*, 20, 1890, 64.
31. *Arch.*, II., 954.
32. *Arch.*, IV., 853.
33. *Loc. cit.*, 20, 1890.
34. *Arch.*, III., 597.
35. *Bull.* 100, *Louis. Univ. Agric. Sep. Station.*
36. *Centralblatt für Bakteriologie*, 13, 729.
37. *Plant Diseases and their Remedies, N.S.W.*, 1893.
38. *Proc. Lin. Soc., N.S.W.*, 27, 31.
39. *S. C.*, 252.
40. *Loc. cit.*, 38, 29, 449.
41. *Medeelingen uits Lands Pantentium*, 1885, II.
42. *Tijdschrift voor Land en Tuinbouw en Boschculture*, 1887 and 1888.
43. *Mededeelingen uits Lands Plantentium*, 1891, **VIII.** and IV.
44. *Die Ziekten van het Suikerriet*, p. 36.
45. *Loc. cit.*, 44, p. 44.
46. *Bull.* 8, *Path. H.S.P.A.*
47. *Arch.*, IV., 209.
48. *I. S. J.*, 41.
49. *Bull. Soc. Mycol.*, XI., 80.
50. *Kew Bulletin*, 1895, 81.
51. *I. S. J.*, 53.
52. *Bull.* 4, *Path. U.S.P.A.*
53. *Rep. Bot. Gdns., B. Guiana*, 1901.
54. *Arch.*, IV., 368, 889.
55. Anonymous Articles in *Revue Agricole de la Réunion*, 1901.
56. *W. I. B.*, IX., 36.

CHAPTER X.

THE HARVESTING OF THE CANE.

Cane Cutting.—At the time of writing the author is unaware of any admittedly successful means of cutting the cane crop except by manual labour; the tools used are the machête or cutlass, views of which are shown in *Fig. 25*. Some of the attempts at improved methods may be briefly mentioned here[1] :—

Paul devised an oscillating knife about 30 inches long, driven by compressed air; Lewis employed a small circular saw; in these devices a portable engine works an air compressor connected by tubing with the tool which is light enough to be carried by one man; the engine follows the operators through the field. The *Hilton Bravo* device is shown in *Fig. 85;* electric power is employed in this case, power being transmitted to the saw by means similar to that employed in the grinding tools of dental surgeons.
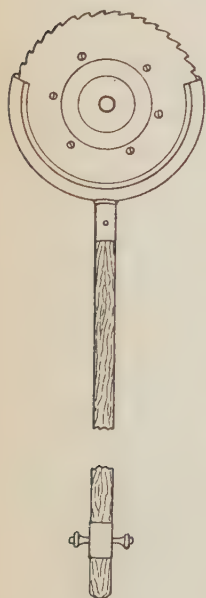
Of the larger power devices, that of Chivers and Hopkins utilized a circular saw, and those of Luce, Gaussiran, and Sloane circular knives; all of these are based on the principle of wheat harvesters and none of them attempted to top the cane. Cockerell's device was an endless chain connected to two traction engines on opposite sides of the field; the chain was dragged across the field by the engines and was at the same time moved in a horizontal plane.

Cane Cars.—A number of years ago the majority of cane cars were constructed with fixed ends and sides made of angle iron; the successful adoption of mechanical train unloading necessitated a change in design. In the Hawaiian islands the cars used are either as shown in *Fig. 87* (PLATE X.) with drop sides, which on being let down form a platform bridging the space from the track to the sunken cane carrier, or else are plain flat cars with sides formed of removable standards; the track is in this case close enough to the carrier to dispense with the

FIG. 85.

necessity of bridging with the drop side. In Mauritius and in Cuba much cane is transported in thirty-ton steel cars on main line standard gauge track; such cars are seen in *Fig. 96* (PLATE XIII.).

Cane Loading.—In most districts the crop of cane after being felled is altogether carried to the carts or other containers by hand; the nature of the cane fields is often such that it is impossible to bring conveyances on to the field, and economy is only obtained by well-considered schemes in the laying out of the plantation roads and portable track. In the Hawaiian islands, the sleds shown in *Fig. 86* (Plate X.) are frequently used to convey the canes to the cars.

Cane loaders or transfers consist essentially of a crane or derrick which may be portable or stationary. The *Wheeler-Wilson* loader is shown in *Fig. 87;* it is operated by means of a gasoline (petrol) motor; the cane is loaded into slings which are elevated by the crane and dumped into the cars.

There are loaders of several designs essentially similar to the above; some are arranged to be moved on a portable track, and others are drawn about the fields by horse or mule power; it is in Louisiana that they have been mostly developed.
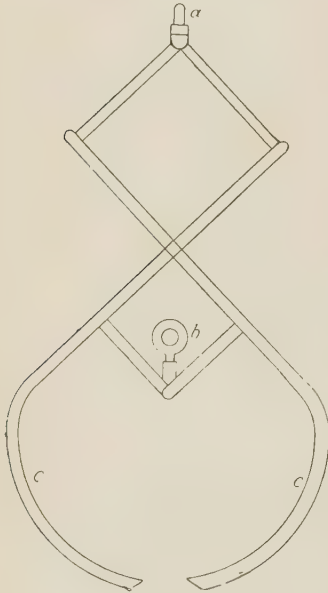
Fig. 88.

Instead of using slings, loaders of similar action to the one described above are made, provided with grabs similar to those originally devised for the loading of hay. A sketch of the grab is shown in *Fig. 88.* It consists of a curved pair of forks *c c;* the system is suspended at *a* by a wire rope; a second rope is attached at *b;* a pull on the rope at *b* causes the forks to open; the grab is then lowered on to a pile of cane, and the rope at *b* being slackened a pull on the rope at *a* lifts the grab with its load of cane; to manipulate cane two or more forks are arranged on a beam suspended from the end of the crane.

A totally different device, which the writer does not believe has ever been extensively adopted, consists of a portable endless belt conveyor arranged at an angle of about 60 degrees from the vertical; the canes are loaded on to the lowest part of the conveyor, and, being carried upward, fall from the highest point of the belt into trucks placed so as to receive them.

In all the designs mentioned above it is necessary to bring the cane to the loader, even to a certain extent in the case of the portable derrick; devices have been designed to rake the cane within a certain radius right up to the lifting device, but such schemes have not been attended with very great success.

PLATE X.

FIG. 86.

FIG. 87.

PLATE XI.

FIG. 89.

In *Fig. 89* (PLATE XI.) is shown a method of transferring a cart-load of cane to a railroad truck by means of a fixed derrick; this view which shows a load being lifted is taken on a Cuba plantation, and a similar method is in use in the Hawaiian Islands.

The mechanical handling of the cane then resolves itself into schemes for the economical transfer of the cane from the field to the receptacles intended for its transport; such complete mechanical harvesting as has been achieved with grain crops does not obtain with the cane.

TRANSPORT OF CANE.—The methods adopted for the transport of cane from the field to the factory may be thus summarized:—

    1. Animal power on roads.
    2. Animal power on tramways.
    3. Animal power on canals.
    4. Mechanical traction on roads.
    5. Mechanical traction on light railways.
    6. Mechanical traction on public railways.
    7. Aerial ropeways.
    8. Fluming.

Animal Road Traction.—This method is now only used on small properties or in larger ones as a means of bringing the cane to a central loading station. The capacity of a mule on the roads usually to be found on plantations is about one-half ton of cane at a speed of two miles per hour; oxen are frequently used, and a typical team and load is shown in *Fig. 90* (PLATE XII.).

Animal Tramway Traction.—Below are given data comparing the cost of mule transport on roads and on tramways.[2]

A tramway was constructed two miles long of two-foot gauge with rails weighing 14 lbs. per yard; the average load in each car was 1900 lbs., the train load averaging 11·25 tons; this was drawn by two mules at a little over three miles per hour; the capacity of a mule on a tramway may then be taken at from fifteen to twenty times its capacity on a road.

The initial cost of the tramways, cars, and stock was $15,900, and of the carts and stock necessary for road transport $15,000. The saving due to the decreased number of animals and carters was $22·75 per day, the cane transported in the same time being 240 tons.

Animal Canal Transport.—This method of transporting cane is used to the exclusion of other methods in Demerara and the Straits Settlements, where the estates are intersected with canals dug for this purpose. The punts used in Demerara are flat-bottomed receptacles, constructed out of wrought-iron plates with heavy wooden bottoms; they are about 25 feet long by 8 feet wide and 3 feet deep, and hold from 2·5 to 3 tons of cane; a mule

will haul four of these punts at a rate of from two to three miles per hour. Water carriage is also employed in parts of Louisiana and of Australia.

Mechanical Road Transport.—Where good roads exist traction engines form a cheap and efficient means of transporting cane. In *Fig. 91* (PLATE XII.) is shown a view of such a scheme. An engine weighing 6 tons and of 20 H.P. will haul 20 tons of cane at a rate of three miles per hour.

Mechanical Tramway Traction.—Undoubtedly the most important and efficient means of transport is a system of light railways. The gauge adopted generally lies between 2 and 3 feet; a gauge of 2 feet 6 inches is one very commonly employed, but for large properties it is more advantageous to have a gauge of not less than 3 feet, as otherwise the number of wagons required becomes excessive. With such a gauge wagons having a platform area of 50 square feet can be used; such wagons will hold from $2\frac{1}{2}$ to 3 tons of cane, a perfectly safe rule being to allow half a ton of cane to every 10 square feet of platform area. A locomotive weighing approximately 15 tons will haul, at a rate of ten to twelve miles per hour, twelve to fifteen wagons, each holding about 3 tons of cane.

The cost of laying down a system of railways to feed a factory is very considerable. The lowest cost per mile for a gauge of 2 feet 6 inches is not less than £300, with rails weighing 18 to 20 lbs. per yard. For a 3-foot gauge, with rails 25 lbs. to the yard, an initial cost of £450 is the lowest which can be expected. These figures do not, of course, include the cost of locomotives and rolling stock. The cost of laying down the rails is entirely dependent on local conditions; where these are favourable, and no expensive cuttings or bridges have to be made, a minimum cost of £100 per mile may be sufficient, an estimate to be greatly increased with unfavourable local conditions.

The following figures, taken from actual practice, will give much information regarding light railway transport:—

Acreage served	2050.
Miles of permanent track	48.
Gauge	3 ft. $1\frac{1}{2}$ in.
Number of locomotives	6.
Weight of locomotives	15 tons.
Number of wagons	175.
Size of wagons	10 ft. by 5 ft.
Load of wagon	2·75 tons.
Number of wagons per train	10.
Cane transported per 24 hours	900 tons.
Average distance of transport	4 miles.
Cane transported during crop	48,000 tons.

Coal burned per ton mile .. ..   4·70 lbs.
Maintenance of line and rolling stock per ton mile ..   ·772 pence.
Fuel per ton mile .. ..   1·536   ,,
Stores per ton mile   .. ..   ·160   ,,
Labour per ton mile.. .. ..   ·740   ,,
Total cost of transport per ton mile .. .. 3·208   ,,

On all the larger plantations in the Hawaiian islands 30-ton locomotives are used, capable of drawing a load of 300 tons of cane ; a typical cane train is shown in *Fig. 92* (PLATE XII.).

Transport on Public Railroads.—In districts where the cane forms an essential staple of commerce the tracks of the public railroads are frequently utilized to transport large quantities of cane, and this method is very efficient ; it is used very successfully in cane-farming districts, the farmers bringing their produce in carts to a siding where the cane is weighed and then transferred to the wagons running on the main line tracks.

This system is used extensively in Mauritius ; the wagons used are similar to those seen in *Fig. 96*, and hold from 15 to 30 tons of cane.

The rates charged there for transport are 10 cents of a rupee per ton per mile for the first, 8 cents for the second, and 6 for the third and following miles.

Aerial Ropeways.—As a means of transport in hilly or broken districts, notably in Mauritius, ropeways find some use. The following description of the ropeways often used in Mauritius is after Wallis Taylor :—

" The arrangement consists of a driving gear at one end or terminal of the line fitted with a driving drum suitably geared to receive rotary motion which, in this instance, is provided by the power of the cane mill, and a similar wheel at the other end fitted with tightening gear, an endless band of wire rope being mounted on these wheels. At intervals of about 200 ft. intermediately between these terminals the rope is supported on pulleys mounted on posts at a suitable height to enable the carriers to clear all intervening obstacles, and to a certain extent also to regulate the general level of the line. The carriers hang from the rope and are enabled to pass the supporting pulleys by means of curved hangers. These curved hangers are pivoted on V-shaped saddles resting on the rope, the saddles having malleable cast-iron frames fitted with friction blocks to enable the requisite friction on the rope to be obtained, and allow the carriers to pass with the rope up steep inclines and over the pulleys, wings at each end of the saddle frames embracing and passing over the pulley rims. The saddle frames are besides each fitted with two small wheels mounted on pins which admit of the carrier being removed from the rope at the terminals, and at curves, on to shunt rails held in such a position that when the carrier approaches the terminal the small wheels will engage on it, and running up a slight incline lift the friction clip saddle from the rope and enable it to pass to the loading or unloading station
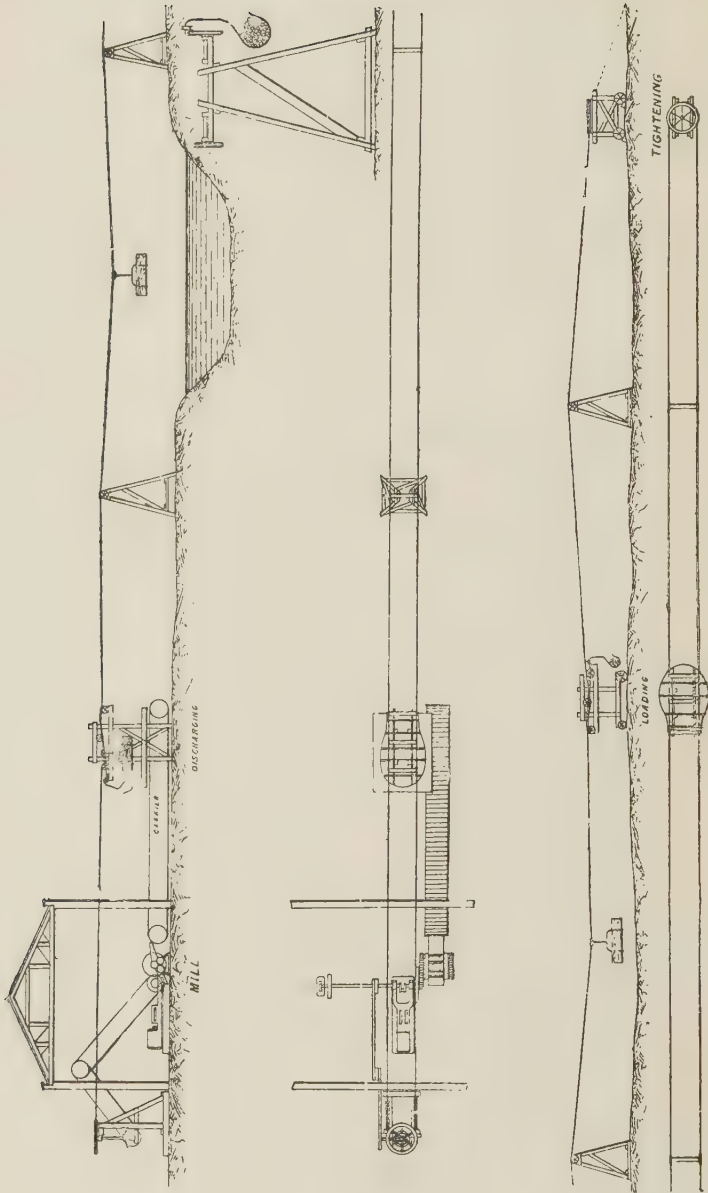
Fig. 93

or round the curve wheels, the impetus derived from the speed of the rope being sufficient for the purpose of enabling the carriers to free themselves automatically from the rope."

Views of this scheme are shown in *Fig. 93*, and a view of the cradle in *Fig. 94*.
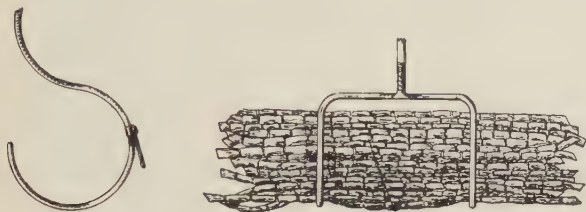
FIG. 94.

The cost of this system to transport 10 tons of cane per hour is roughly £150 per mile, f.o.b., European ports.
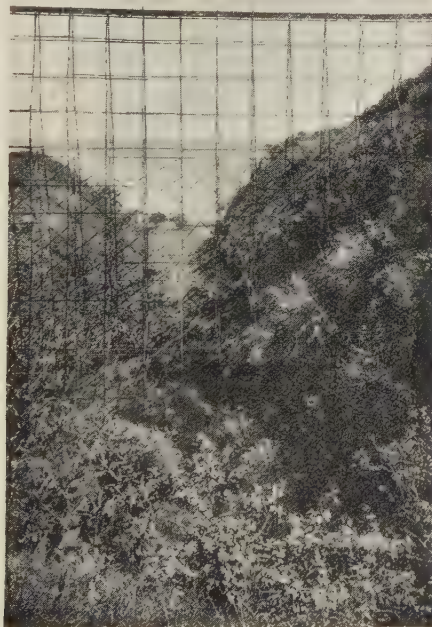
FIG. 95.

In some cases the configuration of the land will allow of a gravity system; in the simplest arrangement the loaded cradles run down a fixed rope and are afterwards packed back to the fields; in another system the descending load works an endless rope which also carries back the empty cradles.

Fluming.—Fluming is a method of transport used to a very consider-able extent in the Hawaiian Islands. A flume consists of a wooden gutter of V section. The material used is pine lumber, 1 in. × 14 in., and for ease of transport is made in 12 ft. lengths; vertical boards 6 in. high are fixed above the gutter. It is supported on light wooden frame work, and ends directly over the end of the conveyor carrying the cane to the crushers. The canes are carried down the flume by means of a stream of water. In *Fig. 95* is shown a view of such a flume. Approximately 1,000,000 gallons in 24 hours will flume 10 tons of cane per hour.

Cane Unloading.—The problem of unloading the cane is a far easier one than that of loading and has been successfully solved in many designs; the appliances used may be divided into those where the load of cane is hoisted bodily from the car, and those where the load is raked from the car.

In the hoisting class, steel chains are placed across the floor of the car, the canes being loaded lengthways across the chains; when the car is in a
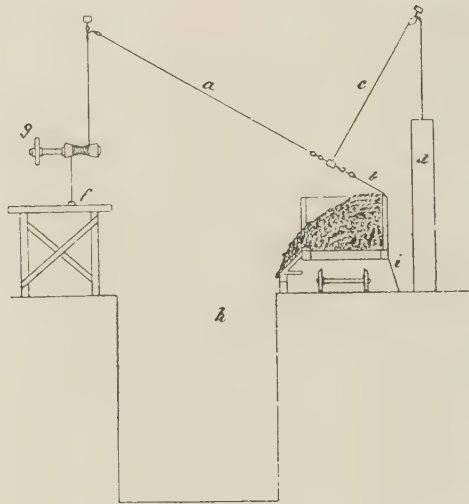
Fig. 98.

position to be unloaded the ends of the chain are pulled out by a hooked rod, battens being placed along the sides of the car to facilitate this; the ends of the sling are then joined and attached to the wire rope of a hoist; the load is lifted and transferred by a travelling crane over a platform or hopper; a pull at a rope opens the attachment of the sling, when the load of cane is dis-charged. This form of unloader has been used by the Link Belt Engineering Co. of New York. In *Figs. 96 and 97** are shown photographs of the installations at Carracas and Francisco plantations, Cuba. In *Fig. 96* the canes in slings are shown ready to be dumped into the hopper; the hoisting

* See *Plates XIII. and XIV.*

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yoke is now parallel with the centre line of the shed; on being transferred by the travelling crane over the cars it is capable of being turned through an angle of 90°. In other factories the position of the cars, with reference to the centre line of the shed, is at right angles to the position shown in *Fig. 97*; the hopper into which the canes are dumped is shown in the same illustration.

A third modification also used by this Company dispenses with the hoist altogether. Slings are placed in the car, as before. The cars are furnished with drop sides, so that a continuous platform to the hopper is provided. The end of the sling, remote from the hopper, is attached to a wire rope passing over a pulley block fixed to the roof of the shed. The car is anchored to the ground, and a pull on the hoisting rope rolls the load of cane into the hopper.

Fɪɢ. 100.

In *Fig 98* is a diagrammatic view of this arrangement; *a* is the hoisting rope receiving power from the sprocket wheel *g*; *b* is the free end of the cane sling; *c* is the counter-weight rope, and *d* the counter-weight box; *f* is the operating platform; *h* the hopper; and *i* the anchor rope.

In another method the cane conveyances are tilted, electric or hydraulic power being used, the canes falling into a pit similar to that in *Fig. 97*; this system is illustrated in *Fig. 99* (Plate XV.). A view of a rake system of unloading cane is seen in *Fig. 100*. The unloading appliance consists of an endless chain passing over a frame which is hinged at its base, and is capable of being raised and lowered. On the endless chain is arranged a series of angle pieces, the whole system of chain and angle pieces forming a continuous rake.

When a car is to be unloaded the frame is made to descend on to the load of cane, and the revolution of the endless chain causes the rakes to drag forward the cane on to the carrier. The cars are sometimes built with a drop side, which being let down forms a platform continuous with the carrier, but this is unnecessary as if the tramway is laid close enough to the carrier the canes fall directly on to the latter, which is of course arranged below the level of the ground.

Another system shown in *Fig. 101* (PLATE XV.) uses in place of the rakes a single row of curved prongs; to the pivoted beam on which these prongs are fixed a simple to and fro motion is given; the beam is also capable of being raised and lowered; this arrangement is independent of the dimensions of the car so long as the latter is not so large as to be without the radius of the beam's action, whereas with the system of the endless chain the dimensions of the car and of the chain have to be correlated.

These cane unloaders are amongst the most efficient labour-saving devices that have ever been introduced into the sugar industry; the capacity of an Asiatic in throwing canes is rather under one ton per hour and these machines with but one attendant will discharge up to 50 tons in the same time.

Loss in Weight of and Deterioration in Cut Cane.—In the modern system of central factories which receives canes from several outlying stations, the question of the loss in weight of canes between cutting and milling is very serious, and very different results will be obtained in the factory dependent on what is considered the weight of cane—the weight at the outlying balance or the weight in the factory yard. As an example, let there be 100 tons of cane as weighed at an outlying station, containing 12 per cent. fibre, and let these canes lose by evaporation 2 per cent. before milling; the percentage of fibre will now be, calculated on a weight of 98 tons, 12·24 per cent., and these canes will give if crushed to a fibre content of 42 per cent., 70·91 per cent of juice, or 68·49 tons from the 98 tons received at the factory; the '*crushing*' is then either 70·91 or 68·49 according to which weight is used; the canes if crushed fresh would have given 71·43 tons of juice.

The average loss per day in fresh cut canes, exposed in heaps of about 50 lbs., is from experiments made by the writer :—

			24 hrs.	48 hrs.	72 hrs.	96 hrs.	120 hrs.
Percentage loss in weight		..	2·73	5·00	6·37	8·81	9·11
,,	,,	,,	2·53	4·49	5·45	8·01	9·01
,,	,,	,,	3·03	3·50	5·19	7·88	8·80
,,	,,	,,	1·59	3·62	4·63	6·26	7·64
,,	,,	,,	1·87	4·48	5·49	6·64	8·02
,,	,,	,,	2·26	4·05	6·11	7·90	8·50
,,	,,	,,	1·41	3·05	5·20	6·09	8·52
Mean ..			2·19	4·03	5·49	7·37	8·57

PLATE XII.

FIG. 90.

FIG. 91.

FIG. 92.

PLATE XIII.
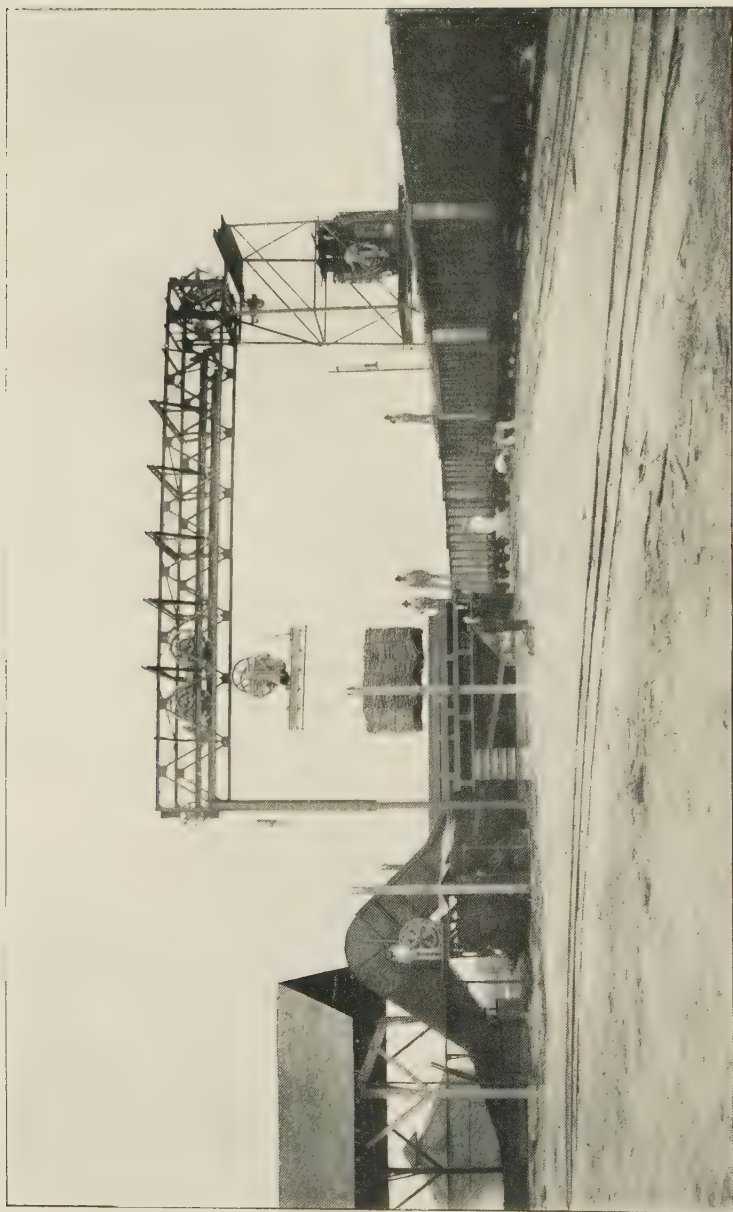
FIG. 96.

Weinberg[3] gives the following data showing the loss of available sugar in cut cane :—

Days cut	0.		1.		2.		3.		4.
Available sugar per 100 A.S. in original sample ..	100	..	97·3	..	92·0	..	78·6	..	67·9
Total loss of A.S.	0·0	..	2·7	..	8·0	..	21·4	..	32·1
Daily loss of A.S.	0·0	.	2·7	..	5·3	..	13·4	..	10·7

It has been shown in Java that cut cane when moist deteriorates much less slowly than when dry ; deterioration is due to the death of the cells which remain alive for long periods when wet. The writer has been informed that in Java, (when, owing to breakdowns in the mill, it is necessary to let large quantities of cut cane stand over) it is usual to cover the cane with trash and to keep it wet by continually deluging the trash with water.

Browne[4] has shown that the sugar in cut cane inverts more rapidly when the immature top is left on ; the inversion takes place under the influence of an enzyme which is present in greatest proportion in the top, and after the cane is cut this enzyme diffuses into the juice of the stem.

REFERENCES IN CHAPTER X.

1. *Jour. d'Agric. Trop.*, 1906-35.

2. *S. C.*, 205.

3. *I. S. J.*, 59.

4. *Louisiana Bulletin*, 91.

CHAPTER XI.

THE EXTRACTION OF JUICE BY MILLS.

Mills, as now constructed for the extraction of the juice of the cane, consist of heavy iron or steel horizontal rollers, driven by a steam engine through powerful spur and pinion gearing. The rollers are set with their centres at the angles of an isosceles triangle, the verticle angle of which is generally about 83°; but, sometimes, mills are met with having a vertical angle considerably greater, even reaching up to 90°. The rollers draw the cane within their grip, subjecting it in its passage to great pressures and causing the rupture of the cells and the expression of the juice; the latter falls on to the bed-plate of the mill, whence it flows into a well and is pumped up to the clarifiers for further treatment.

In almost all recently erected factories, the milling plant consists of not less than nine rollers combined in three mills, the whole combination being driven by one engine. In several instances, notably in the Hawaiian Islands, twelve-roller combinations have been installed; in one case each in the Hawaiian Islands and in Porto Rico, 15-roller combinations are employed, or, including the crusher, 17 rollers. This last scheme, which is at work at the well known Ewa and Guanica plantations, is a 15-roller mill in operation but not in construction. At first the Ewa plant consisted of two nine-roller mills placed side by side; as afterwards arranged the canes pass through one of the original sets, and are then transferred by a cross carrier to the second mill of the other set; in case of stress the original method can be used. This scheme is the result of empiricism in regard to the capacity of mills. A number of years ago it was thought that a mill 34 in. × 78 in. was run at its maximum capacity when about 35 tons of cane were ground per hour; but provided the mills had enough engine power, it was found that much larger quantities could be worked without detriment to the efficiency, and hence came the idea of utilizing the existing train of mills to the best advantage, since the extraction, as is shown later, increases with the number of crushings, the quantity of water added remaining the same.

In twelve-roller combinations that have been formed by the addition of a three-roller to existing plant the last mill is usually provided with its own engine; in others that have been laid down to one design a separate engine is provided for each six-roller unit, the earlier one driving also the crusher or shredder. In older plants, especially in those which have been built up

piecemeal, each mill is driven by its own engine; the advantage of the single motor type lies in the synchronized working of each unit and in economy in steam and supplies and labour.

The Three-Roller Mill.—The first mill with three rollers with the centres arranged at the angles of an isosceles triangle was made in 1794 by Collinge; in its modern form the headstock or housings on which the rollers are supported may be considered as derived from a rectangle of rather less height than breadth, gaps or openings for the insertion of the gudgeons of the rollers being arranged symmetrically on the top and sides of the rectangle. In *Fig. 102* is shown in outline in half elevation the evolution of the conventional form of headstock; *a* represents a solid or rigid headstock of massive construction and characterized by an exceedingly flat vertical angle. The difficulty of removing a roller led to the insertion of a distance piece in the shoulder of the headstock, the horizontal strain being taken up by a bolt

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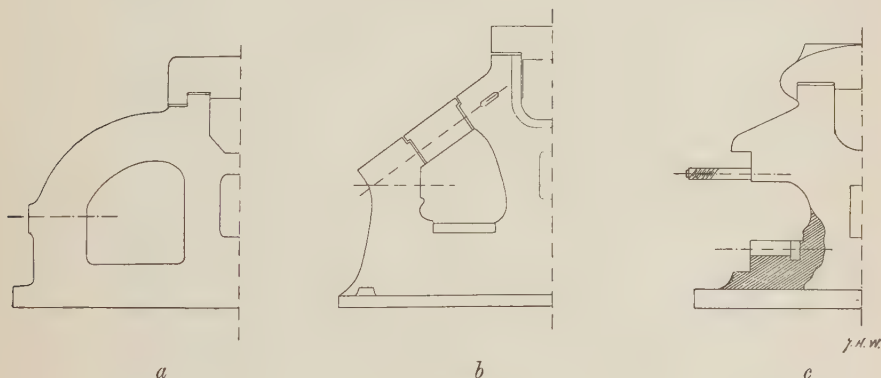
Fig. 102.

passing therethrough, as shown at *b*; the modern form of headstock is seen at *c*, where the set screws controlling the horizontal outward movement of the bottom rollers are replaced by caps bearing directly on the brasses on which rest the roller gudgeons; the caps are held in place by heavy T headed bolts recessed into the headstock.

In all these patterns tensile strains occur in the headstock which is constructed of material unsuited therefor. The radical improvement is due to Rousselot, a French engineer, of Martinique, who, while retaining the form shown at *c*, passed the side cap bolts through the headstock whereby the horizontal strains are taken up by the bolts which are constructed of material adapted for that purpose.

In the original *Rousselot* mill four side cap bolts were employed; these passed without the vertical bolts; indifferently four vertical bolts may be used between which pass the horizontal or *Rousselot* bolts; another modification

consists of slotting either the vertical or horizontal bolts so that the whole system lies in one plane. In the Delbert design, *Fig. 105*, but one horizontal bolt is used, and it is entirely absent in the Krajewski-Pesant design shown in *Fig. 107*.

In *Figs. 103* and *104* are given side and end elevations of a modern Rousselot mill; the principal parts are the headstocks or mill cheeks, the rollers, the caps or keeps, the sole plate or bed plate, and the trash or dumb turner. The headstocks *b* are heavy solid castings; in them are three openings—one at the top and one at each side, which serve for the intro-
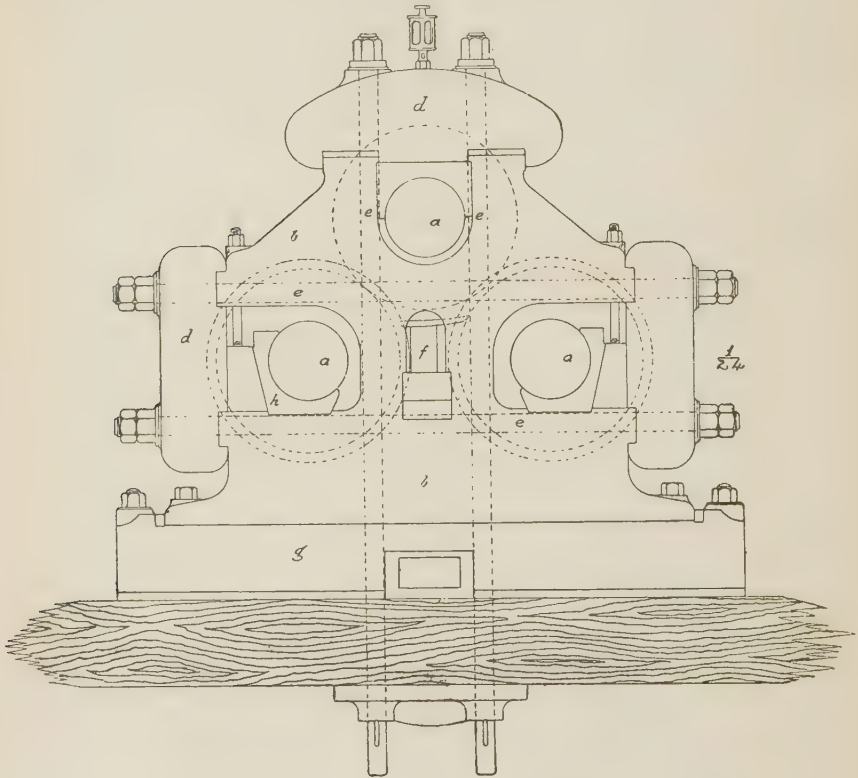
Fig. 103.

duction of the rollers *a*. The rollers consist of a shell of iron or steel, which is forced by hydraulic pressure on to the shaft or gudgeon; formerly the shell was hung on the shaft by six or eight keys, and occasionally in old mills square shafts are to be met with. The shaft, which is also called the gudgeon, is constructed either of hammered scrap-iron, wrought-iron, or in the most recent designs, of fluid compressed steel. The shafts are nearly always made solid, as no benefit is obtained by a light, hollow shaft, and it is desirable to keep their diameter as small as possible, consonant with sufficient strength. The shafts rest on brasses *h* of gun metal of large

bearing surface; to one end of the shafts are keyed pinions gearing into each other, by means of which motion is transmitted from the top shaft to the two lower rollers. Generally mills are geared on one side only, but occasionally gearing is found on both sides. The rollers are kept in position by the caps d; through these caps pass throughway bolts, which keep the caps pressing on the bushes. The position of the rollers is adjusted by means of these bolts. The headstocks rest on the sole plate g, to which they are securely bolted; all the vertical bolts pass through the foundation, and act as holding down bolts; the partially crushed cane coming from the top and
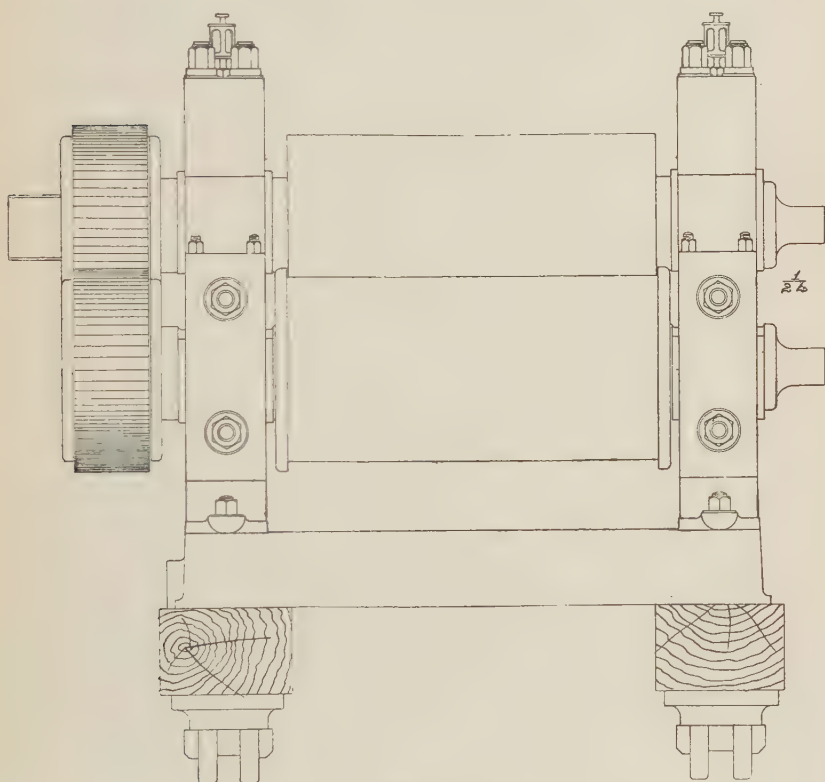
Fig. 104.

front rollers is directed to the top and back rollers by the trash turner, which consists of two parts, the trash bar f and the trash plate, the curve of which is also shown.

Solid Headstock Type.—The older type of three-roller mill is seen in *Fig. 105*, and is referred to as closed headstock or rigid pattern; the side rollers are kept in place by set screws, passing horizontally through the headstock. Mills of this type are still occasionally built, and so far as '*crushing*' is concerned, perform as well as the more elastic open headstock

pattern. They are, however, inconvenient to handle in the event of removing a roller, and from their rigidity are more liable to fracture in case of any unforeseen strain.

Stillman Mill.—In this pattern the vertical bolts are replaced by a U bolt recessed into the mill cheek; in other respects the conventional or standard pattern is followed.

Allan Mill.—In this pattern the trash turner is absent entirely ; this mill may be described as an ordinary three-roller mill turned through an angle and with the original top roller reduced in size ; the two side rollers
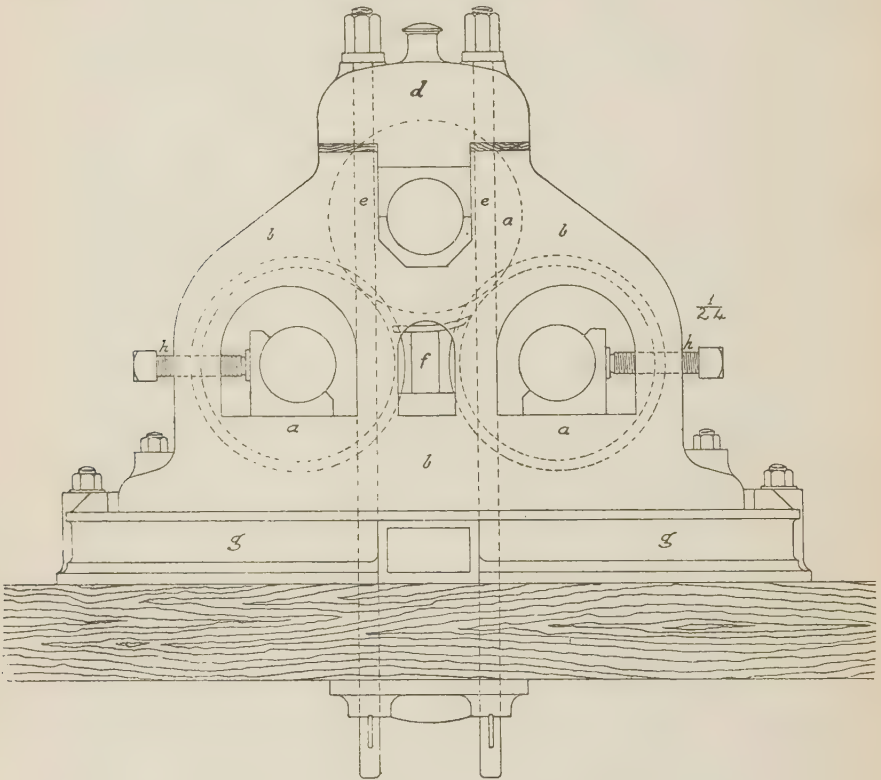
FIG. 105.

then come nearly in the same vertical line with the centre of the original top roller and approximately in the same horizontal line as the line of contact of the other two rollers ; the small roller is then able to act as a feeding roller to both the large rollers.

Inclined Bolt Type.—In some mills recently built by the Fulton Iron Works the holding down bolts are bent and converge from a line below the top roller journal to a point on a level with the seat of the lower roller journal after which they again become vertical and pass through the bed

plate. The original inclined throughway bolt mill was, the writer believes, built by Fawcett, Preston & Co., under one of Chapman's patents.

External Bolt Type.—Mills are exceptionally found with the vertical bolts passing without the shafts of the lower rollers, the top cap being extended so as to receive them.

Delbert Mill.—This mill, shown in *Fig. 106*, has a triangular head-stock, the usual vertical holding down bolts being replaced by bolts inclined to each other at 60°, which do not pass through the bed-plate; these bolts lie parallel with the lines joining the centres of the top roller and a lower roller and hence in the direction of the principal strains; the hydraulic is applied on the top cap and a very narrow trash bar is obtained.
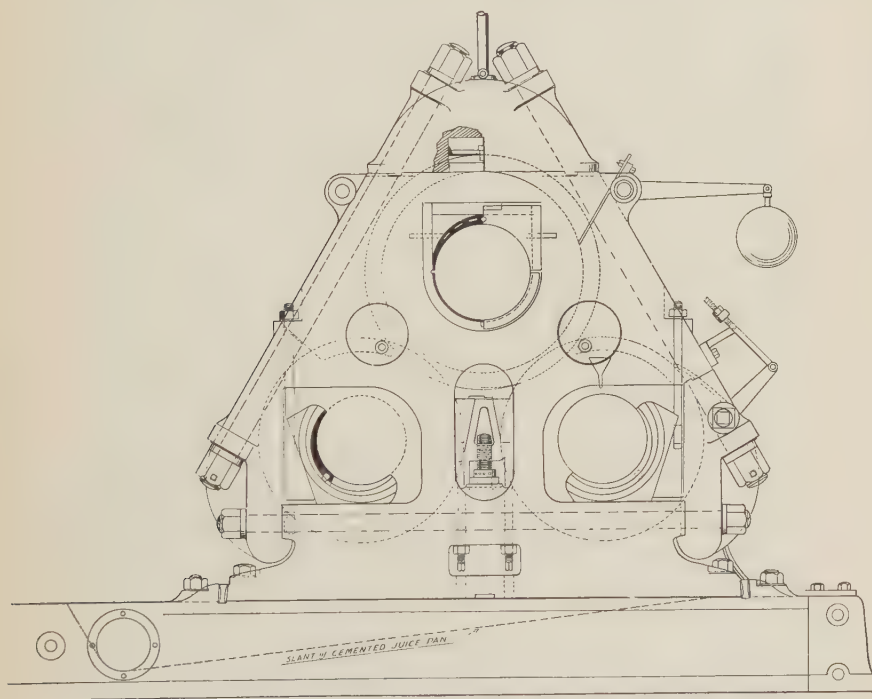
FIG. 106.

Krajewski-Pesant Mill.—A radical departure from conventionalism is shown in the headstock adopted by the Krajewski-Pesant Co. in the H-type of mill illustrated in *Fig. 107*. The headstock is of triangular form; the hydraulic pressure is applied to the back roller and in a line at right angles to the layer of megass; in this way the whole amount of the pressure is exerted upon the megass; the back roller may be said to float upon the ram of the hydraulic, the movements of which it will follow with a minimum lag due to reduced friction between the brass and the surface upon which it rests; in the conventional mill the brass rests on a horizontal surface. Both front and back

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rollers rest on surfaces at right angles to the direction of pressure, so that the resolved force tending to push the rollers outwards is zero, and the necessity for horizontal bolts disappears. The vertical throughway bolts are inclined towards each other from above downwards giving a very narrow trash turner.

Hall's Inclined Headstock Mill.—A mill of the design shown in *Fig. 107a*, was put in operation at the Puunene factory of the Hawaiian Commercial and Sugar Company in 1909 ; the principle involved in
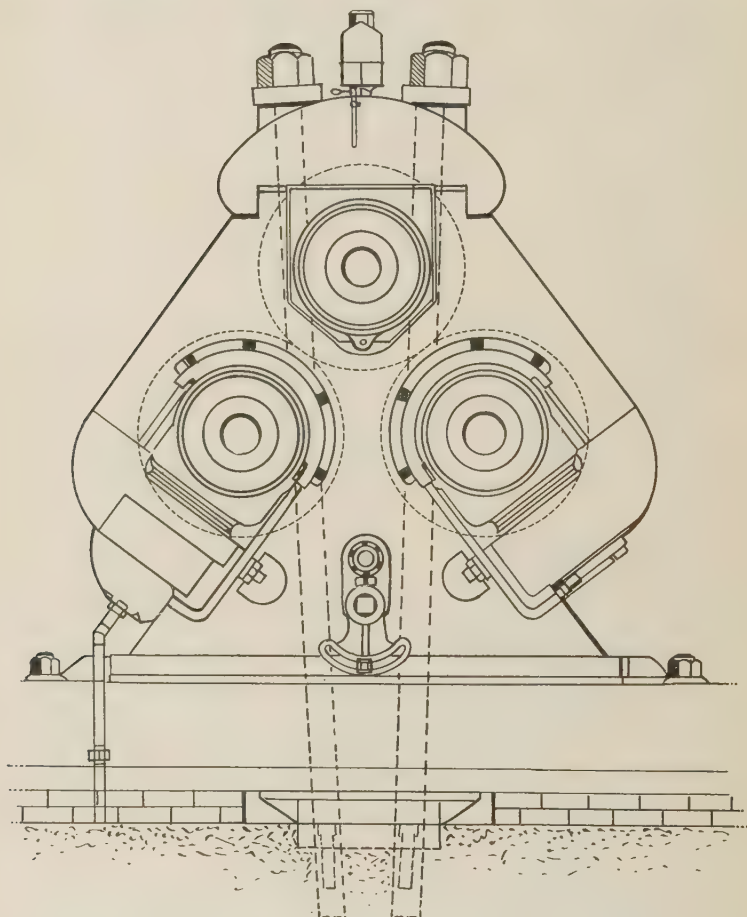
FIG. 107.

this design is the placing of the king bolts and of the hydraulic pressure in the same line as the resultant of the stresses caused by the pressure between the top roll and the front and back rolls. If the stresses between the top roll and front roll, and top roll and back roll, were equal, the top roll would tend to lift vertically ; owing however to the greater stress between the top roll and back roll, there is a tendency to push the top roll upwards in a
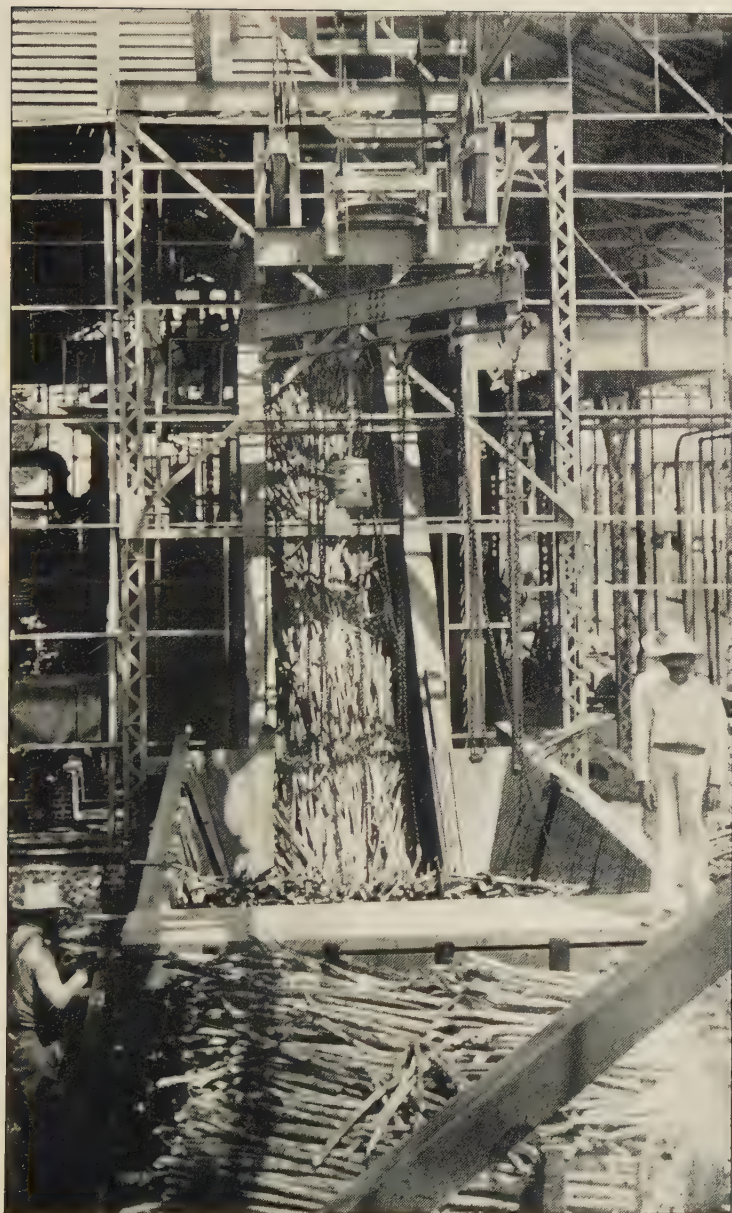
PLATE XIV.

FIG. 97.

PLATE XV.

FIG. 99.
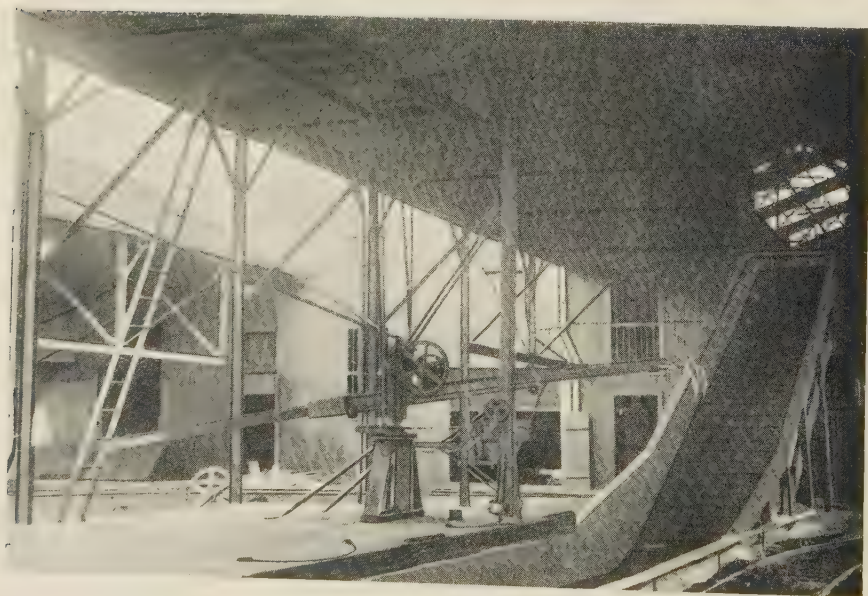
FIG. 101.

direction inclined towards the front roller; in this design the hydraulic pressure acts in a line nearly continuous with that joining the centres of the top and back roller, and hence exerts a greater effective pressure on the layer of megass than when it is applied vertically.

Fogarty Mill[2].—This mill, shown in *Fig. 108*, completely departs from conventionalism, the standard type of headstock being replaced by an all steel circular housing
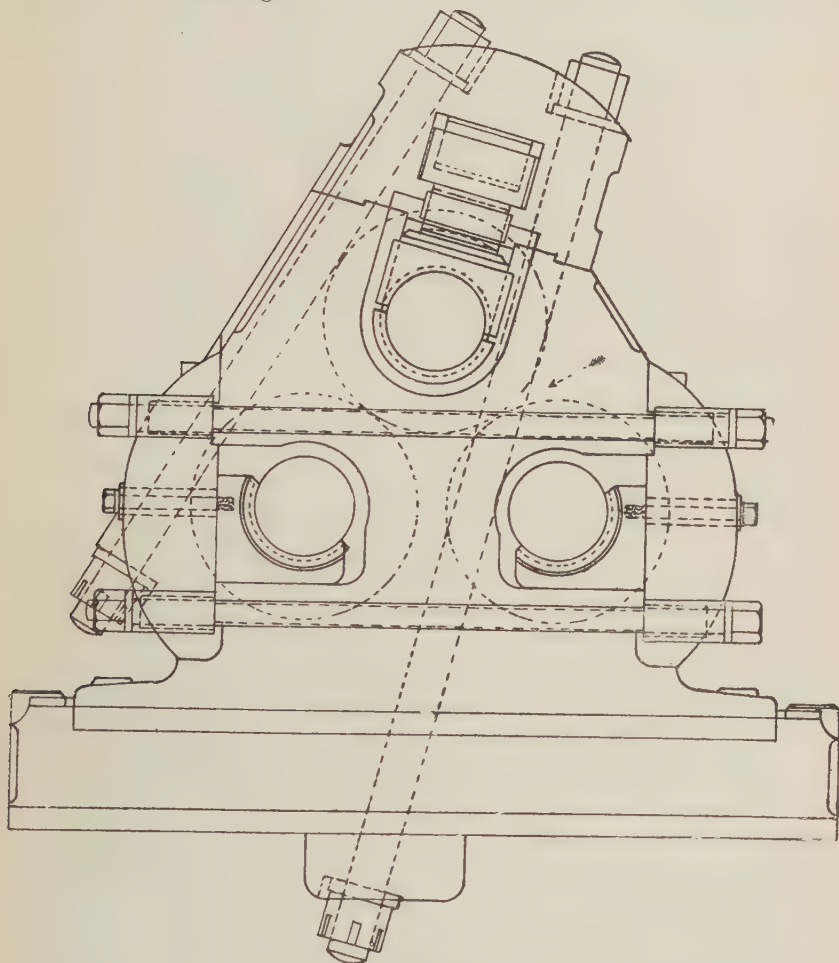
FIG. 107A.

The Two-Roller Mill.—Two-roller mills, *Fig. 109*, have had many advocates, who held that the strains would be more evenly distributed, and that the power lost through the trash turner would be saved. In addition, the rollers being in the same vertical line, it was argued, perfectly correctly, that the whole of the pressure keeping down the top roll would be exerted in crushing the cane; experience has shown, however, that they are not

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successful, one very potent objection being that the rollers cannot be set close, else the mill refuses its feed; whilst in a three-roller mill, the front roller acts as feeding roller to the back one. Two-roller mills were advocated by Rousselot in Martinique, and by Alexander Young in the Hawaiian Islands, as 'macerating' mills to be used after a three-roller mill.

Four-Roller Mills.—Of four-roller mills, which have never come into general use, the best known are the *De Mornay* and *Le Blanc*. The
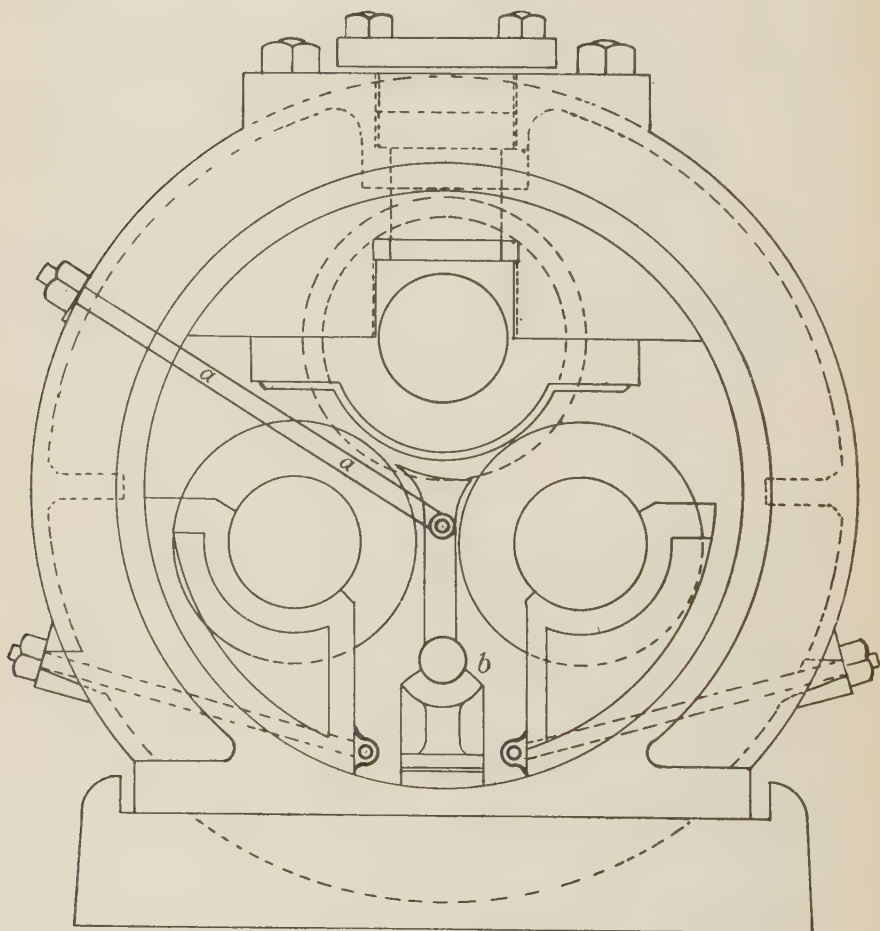
Fig. 108.

former, which has been erected to some extent chiefly in Peru, Argentina, and Brazil, is shown in *Fig. 110*. It consists of two main rollers *a* and *b*, and two supplementary rollers *c* and *d*. The cane is crushed three times, between *a* and *c*, *a* and *d*, and *a* and *b*; no trash turner is required. This mill has given good results with long jointed canes, but with short jointed hard brittle canes it has not been successful.

The *Le Blanc* mill is shown in *Fig. 111.* It consists of a main central roller *a*, round the periphery of which are placed three other rollers *b, c, d;* the cane passes between each of these and the main central roller, so that it is crushed three times. Two trash turners *e* are required.

Five-Roller Mills.—The five-roller mill, which is frequently mentioned in the ephemeral literature of the cane, is merely a typical three-roller mill in which the headstocks are extended so as to receive a pair of rollers which are placed above and in front of the three-roller mill; the shaft
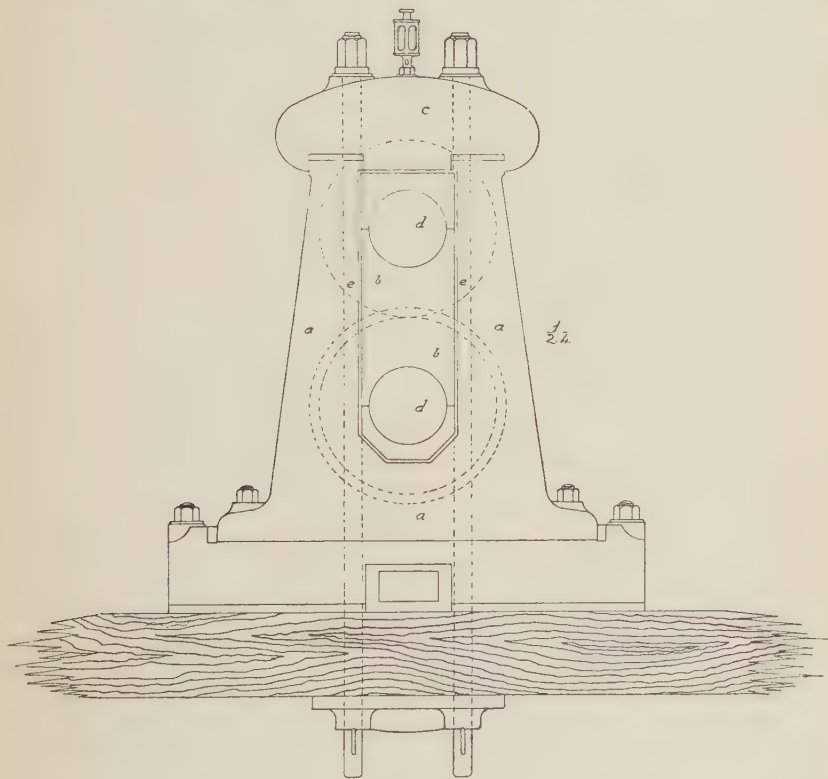
FIG. 109.

of the top roller of the mill proper is extended on one side so as to receive a large spur wheel, which gears with one of equal diameter on the gudgeon of the top of the two preliminary rollers. On the other side of these rollers are pinions gearing with each other, by means of which motion is transmitted to the lower of the two rollers.

Nine, Twelve, and Fifteen-Roller Mills.—These terms merely refer to the number of rollers in a train and not to the number of rollers in a unit. The addition of a unit to an existing train has a two-fold effect, namely, in increasing both the extraction and the tonnage worked. The writer's experience of these combinations may be thus summed up.

A nine-roller mill and crusher of size 30 in. × 60 in. will treat 20 tons of cane per hour, and with mixed juice equal in weight to cane will give an extraction of 93·5, the canes containing 12 per cent. of fibre; a mill 34 in. × 78 in. will give the same results with 35 tons of cane per hour.

A twelve-roller train 30 in. × 60 in. under equal conditions will give an extraction of 95·0.

A fifteen-roller train 30 in. × 60 in. under equal conditions will give an extraction of 96·0.

A twelve-roller train and crusher 34 in. × 78 in. will treat up to 50 tons of cane per hour and give an extraction of 94·5 under the same conditions as before.
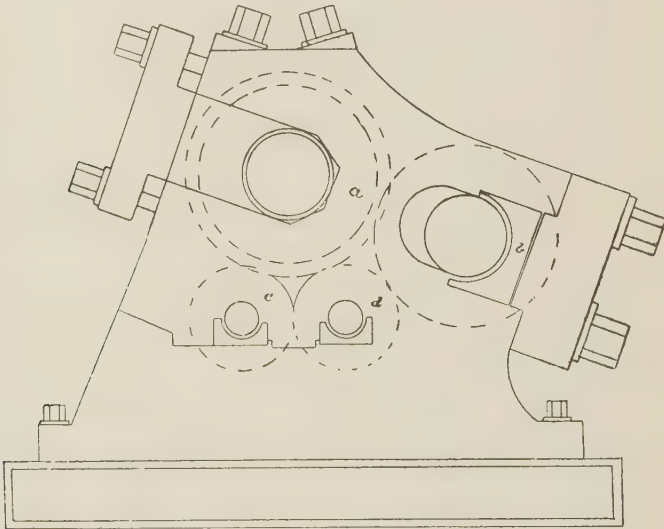
Fig. 110.

A fifteen-roller train and crusher 34 in. × 78 in. will treat up to 60 tons of cane per hour and give an extraction of 95·5 under the same conditions as before.

The Motive Power of Mills.—With the exception of a few instances in unprogressive districts, steam is the agent used to drive sugar mills; wind power is still employed to some extent in Barbados, and where water power is available no objection can be made to its use. Electrically-driven mills still belong to the future, but the design of one prime motor, to drive electrically all the machinery in a factory, offers no great difficulty; and, where water power is available, the design of a system of turbines, dynamos, and motors to drive all the engines and pumps in a factory without burning any fuel for motive power, is quite feasible, and milling plants have been erected where the motive power is derived from a fall of water through a Pelton wheel.

The engines used to drive sugar mills are either beam engines or horizontal engines; generally, owing to the type of labour available, the design of the engines is as simple as possible. Whether beam or horizontal, they are nearly always simple non-condensing engines, the exhaust steam being used in evaporation. Beam engines make a handsome ornament to a factory, but they are more expensive in first cost; their cylinders, however, do not require re-boring. The horizontal engines used are nearly always single cylinder engines; occasionally, when the engine is at a dead centre, the cane mill chokes, and it may be necessary to lever the fly-wheel round to allow the engine to re-start. A two-cylinder engine, with cranks set at right angles, would overcome this difficulty, and the writer has seen such an installation at work in a modern mill; but in all the recently erected mills in the Hawaiian Islands single cylinder non-condensing engines of the Corliss type have been erected.
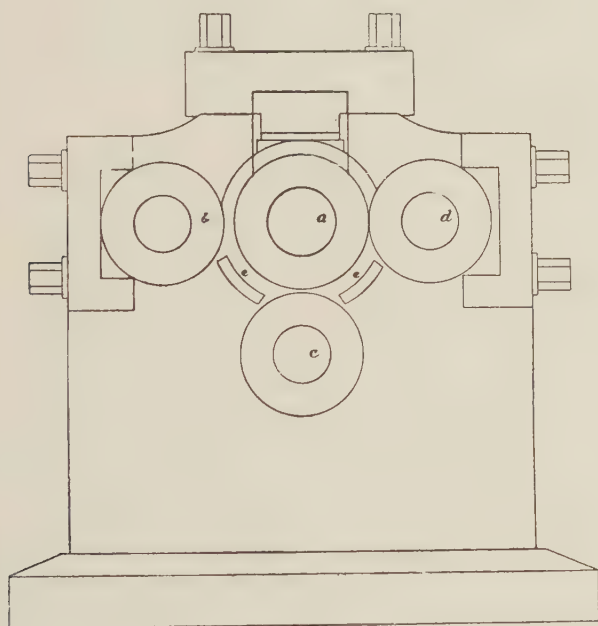
Fig. 111.

The Gearing of Mills.—The intermediate gearing which transmits power from the engine to the mill consists of heavy toothed wheels; occasionally helical teeth are employed. Except in small mills the spur wheels are built up in segments; usually there are from six to eight arms, to which are bolted the segments of the gearing; the pinions are cast in one piece, and are usually half shrouded. In *Figs. 112 and 113* are shown two methods of connecting up the gearing of a single motor nine-roller mill; a is the fly-wheel, b_1 the first motion pinion, c_1 the first motion spur wheel, b_2 and c_2 the second motion pinion and spur wheel. In *Figs. 112 and 113*, b_1 transmits motion to both spur wheels,

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which in turn convey power to the spur wheel c_2 by the pinion b_2. The ratio of gearing is 20 : 1, and with an engine revolution of 40 per minute gives a peripheral speed to the rollers 30 inches in diameter of 15·7 feet per minute. In the plan as arranged in *Fig. 112*, a much more compact train of gearing results, and this is the form usually adopted in modern plants. As a modification, the first motion gearing can equally well be connected to the pinion between the first and second mills, and in the scheme in *Fig. 113* the greater distance between the two mills may be between second and third or first and second, dependent on whether the mill at extreme right or left is considered to be the first mill; in either case the distance between the two mills closer together can be increased by increasing the size of the spur wheel without altering the speed of the mill.
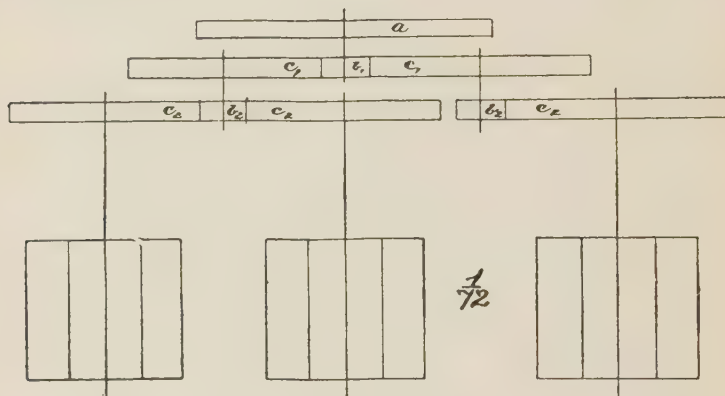
FIG. 112.

The purpose of the arrangement in *Fig. 113* is to obtain a means of complete maceration in baths between the mills, an object which cannot be attained by the more compact system illustrated in *Fig. 112*. This question is discussed at greater length further on.

It is now the rule, in single motor driven plants, to so arrange the gearing that there is an increase in speed from mill to mill; in the Hawaiian Islands it is customary to find peripheral speeds in the mill rollers of about 20, 23, and 26 ft. per minute in the first, second, and third mills respectively; formerly much lower peripheral speeds were customary.

The Trash Turner.—The object of this appliance is to direct and guide the partially crushed cane between the top and back rollers; it was invented by a Barbados planter called Bell, the operation having previously been performed by negroes. The trash turner consists of two parts, the trash bar and the trash plate; the trash bar consists of a massive iron or steel casting; it may be of rectangular, pear or of I section; in older mills it is often found supported on openings in the headstocks, as in *Fig. 102*. In more recent patterns it is carried on chairs cast on the inner side of the

headstocks ; these chairs may be a plane surface in which case the adjustment of the trash turner is effected by the insertion or removal of wedges.   In yet more recent designs the trash bar is mounted on a trunnion bearing as seen at b in *Fig. 108* ; its adjustment being made by means of the lever as a bearing on the mill cheek.
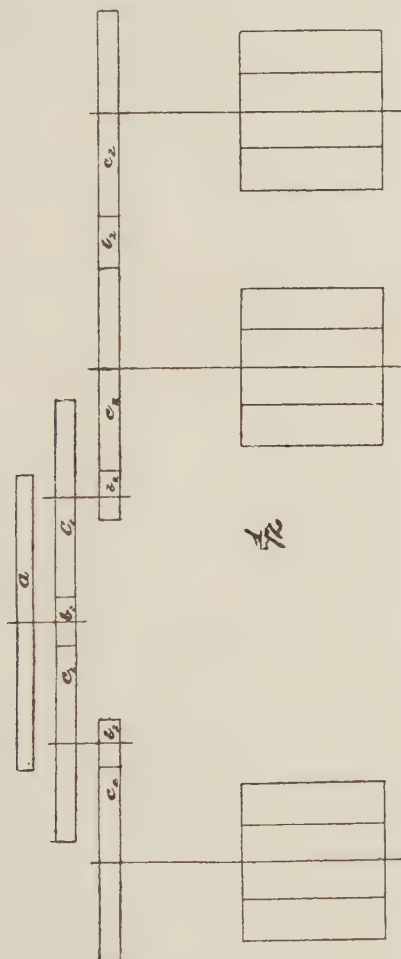
FIG. 113.

The size and setting of the trash turner is a point of very considerable importance.   In the first place its object is to direct the partially crushed cane between the top and back rollers, and it is usually set sloping slightly downwards in the direction in which the cane travels.   If it is set too close to the rollers, there is insufficient room for the blanket of megass to pass without causing enormous friction, and if set with too great a clearance it ceases to perform its proper functions.   As friction depends on the area of

contact, its width should be as small as possible. The width of the trash turner is determined by what may be called the vertical angle of the mill, *i.e.*, the apex of the triangle formed by joining the centre of the rollers; the larger this angle, the wider the trash turner. In actual practice, vertical angles lying between 75° and 90° are met with, a very general angle being about 82°-84°. In addition to a small vertical angle diminishing the width of the trash turner, the component of the downward pressure exerted vertically on the top roller, on the line joining the centres of two rollers, is greater. There is a limit, however, to decrease in the vertical angle since, as this narrows, the space available for the shaft of the lower rollers becomes less. By the employment of the best material, mills with small shafts of sufficient strength and narrow trash turners can be made.

A very large number of curves has been suggested for the trash turner, in all of which the personal equation of their originators appears very largely. On certain mathematical grounds it can be shown that the correct curve is a logarithmic spiral, the construction to obtain which is given below. The method which appeals most to the writer is one of trial and error :—indicating the engine with different settings, and adopting that setting which is found to absorb least power. Another essentially practical method is to adopt that curve into which an old trash plate has been worn. It must be borne in mind, however, that the proper curve and setting is dependent amongst other things on the nature of the canes ground, particularly on the amount of fibre and on its mechanical structure and resistance to compression, so that a setting satisfactory with one lot of canes may be the reverse with another ; continual watchfulness on the part of the engineer is called for here.

The efforts of engineers have been directed largely in late years towards diminishing the width of the trash turner, and towards obtaining at the same time a small apex to the mill; all the departures from conventionality instanced above have had this point in view.

Bergmans' Theory of the Trash Turner[3].—The following mathematical treatment of the trash turner was published in 1889, by R. F. Bergmans and is here reproduced :—

The duty of the trash turner in sugar mills is to direct the crushed cane from the first cylinder pair (one and two) to the second (two and three). The crushed cane must be so guided that cylinder *3* can take the feed without stopping the working of the plant.

Let T_1 represent the speed with which the crushed cane leaves the first cylinder pair and T_2 that of the bagasse leaving the second cylinder pair (see *Fig. 114*); then must always $T_1 = T_2$ and it hence follows that the passage of the bagasse over the trash turner must be uniform.

Consider the movement of a point p (*Fig. 115*); using a system of polar co-ordinates the point p will reach A in time t with a velocity V; this velocity can be divided into two components c and w, of which c is in the direction of the radius vector and w is perpendicular to it. The crushed cane must move over the trash turner in such a way that these components are constant, a result to be obtained by the following conditions :—
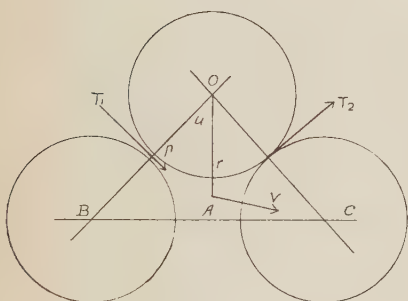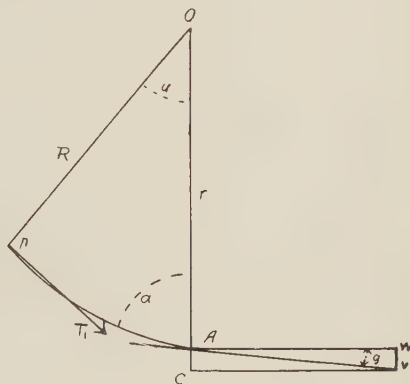

Fɪɢ. 114.   Fɪɢ. 115.

If r and u are the polar co-ordinates of the point p, then

$$C = \frac{dr}{dt} \qquad \text{or} \qquad dr = c\,dt,$$

now, since C is constant, one obtains by integration

$$r = ct + C_1.$$

The value of C_1 is obtained by considering that when $t = o$, r must be equal to R. Using these equalities it follows that

$$C_1 = R$$
$$r = ct + R \qquad .. \qquad .. \qquad .. \qquad (1)$$

Further

$$w = \frac{r \cdot du}{dt}$$

or $w \cdot dt = r \cdot du.$

The value of r can be obtained by substitution from (1) whence it follows that

$$w \cdot dt = (ct + R)\,du$$

or $\dfrac{w \cdot dt}{ct + R} = du.$

On integration $u = \dfrac{w}{c} \log (R + ct) + C_2.$

The constant C_2 can be obtained by putting $t = o$ and $u = o$, whence

$$C_2 = \frac{w}{c} \log R.$$

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Substituting this value of C_2 it follows that

$$u = \frac{w}{c} \log (R + ct) - \frac{w}{c} \log R$$

or $\qquad u = \frac{w}{c} \log \frac{R + ct}{R}$ $\qquad$ .. $\qquad$ .. $\qquad$ .. $\qquad$ (2)

Whence from (1) and (2) it follows that

$$u = \frac{w}{c} \log \frac{r}{R}$$

or $\qquad \log \frac{r}{R} = \frac{c}{w} u$

If, for simplicity, m be written for $\frac{c}{w}$, and if R be put equal to (1), this equation reduces to $\qquad \log r = m \cdot u$

or $\qquad r = e^{mu}$ $\qquad$ .. $\qquad$ .. $\qquad$ .. $\qquad$ .. $\qquad$ (3)

The equation (3) is none other than that of the logarithmic spiral where e is the base of the natural system.
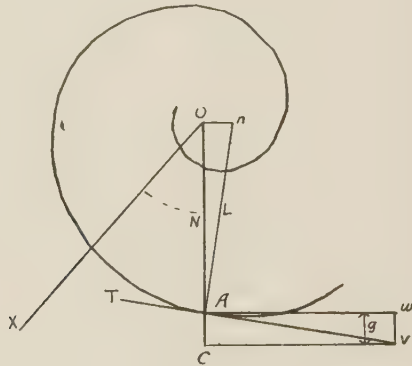
F$_{IG}$. 116.

This curve has the property that the radius vector always makes with the tangent a constant angle; thus the angle a is constant. Now (see *Fig. 116*),

$$m = \frac{c}{w} = \tan g$$

and $\qquad g = 90° - a$

then $\quad m = \cot a = \text{constant.}$

Draw ON perpendicular to OA, and AN perpendicular to T.

Then $\qquad ON = r \cot a = rm.$

In addition $NA = r \dfrac{r}{\sqrt{1 + m^2}} = \dfrac{r}{\sin a}$. Equation (3) gives the path which the point p describes as a logarithmic spiral; for sugar mills this curve is of definite length.

The path, then, which the point p and also the crushed cane describes is a part of a logarithmic spiral; in order to obtain this path for sugar mills the velocities w and c must be known. The velocity w, which is perpendicular to the radius vector, is always equal to T, the velocity with which the bagasse leaves the first cylinder pair. The velocity c is to be determined experimentally, and depends on the elasticity of the crushed cane, and that the cylinder 3 must easily carry forward the bagasse. Before determining empirically the values of c and of the angle a, we will look first at the following considerations :—

In *Fig. 117*, S is the opening between the cylinders 1 and 2, and d is the thickness of the crushed cane, and when the cane is not elastic d is equal to S: in this case the velocity C can be put equal to O for there exists absolutely no
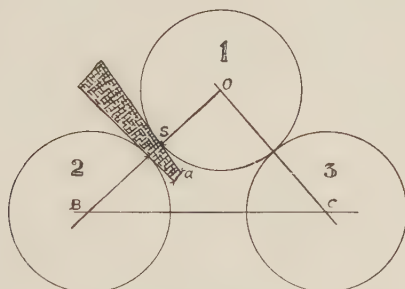
Fig. 117.

reason why the crushed cane should proceed with a velocity C lying in the direction of the radius vector in order that it should easily and without excessive friction pass over the trash turner. When $c = o$, m also $= o$, and $a = 90$. It then follows

$$r = c = 1 = R \quad \text{or} \quad r = R = \text{constant}.$$

In this case the trash turner is a circle of radius $r = R = \dfrac{D}{2} + s$, where D is the diameter of the roller cylinder.

In practice such a condition never occurs, due to the pressure between the top cylinder and the trash turner following on the elasticity of the crushed cane.

This is why C must always be greater than 1. If C becomes too great, then the cylinder 3 cannot take the feed and will cause a stoppage. The velocity C must be such that the angle A is somewhat less than 90°.

The trash turner curve following this argument of Bergmans can be found graphically with close approximation as follows :—

Draw the positions of the rollers to scale, *Fig. 118*; join *OB* and *OC*; draw *KT* parallel to *OC*; draw *KN* perpendicular to *KT*, cutting *OC* at *N*; with *N* as centre and *NK* as radius draw an arc *KM*; then *KM* is very close to the original logarithmic spiral.

J. N. S. Williams[4] gives the following data regarding a nine-roller mill at Puunene, in the Hawaiian Islands :—

	First Mill.		Second Mill.		Third Mill.
Pressure on top roller, tons	230	..	320	..	400
Distance of trash plate from top roller.. ..	2 in.	..	1·5 in.	..	1·25 in.
Opening of top and front rollers	1·125 in.	..	·625 in.	..	·3125 in.
Opening of top and back rollers	·4375 in.	..	·25 in.	..	·0625 in.
Distance between trash plate and back roll ..	1·25 in.	..	1 in.	..	·75 in.
Speed of rollers, feet per minute	20	..	23	..	26

Engine:—60 in. × 30 in. Working pressure at boilers 83 lb. per square inch. Average horse-power developed, 317·86. Revolutions per minute, 48. Tons of cane per hour, 50·28 short tons.
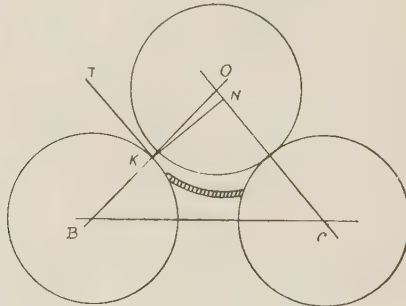
FIG. 118.

In Java, a distance between trash turner and top roller, measured along the vertical line through the centre of the latter of about 55 mm. (2·45 inches) for mills 30 in. × 60 in. (crushing about 600 tons in 24 hours) has been found very satisfactory; for every 1000 piculs (60 tons) increase in cane milled per 24 hours, the distance between trash turner and top roller is increased 3 mm. ($\frac{1}{8}$ inch) or so.

Proportions of Mill Rollers.—A very general proportion for the size of rollers is that the length be twice the diameter. Increasing the diameter of the roller calls for greater power to drive, and at the same time increases the tendency to fracture, due to torsional strains; at the same time the gudgeons can be made larger, and whereas the torsional strain only increases directly with the diameter, the strength of the gudgeon increases proportionately to the square of the diameter. Another objection to rollers of large diameter is that the trash turner also becomes larger, and the friction
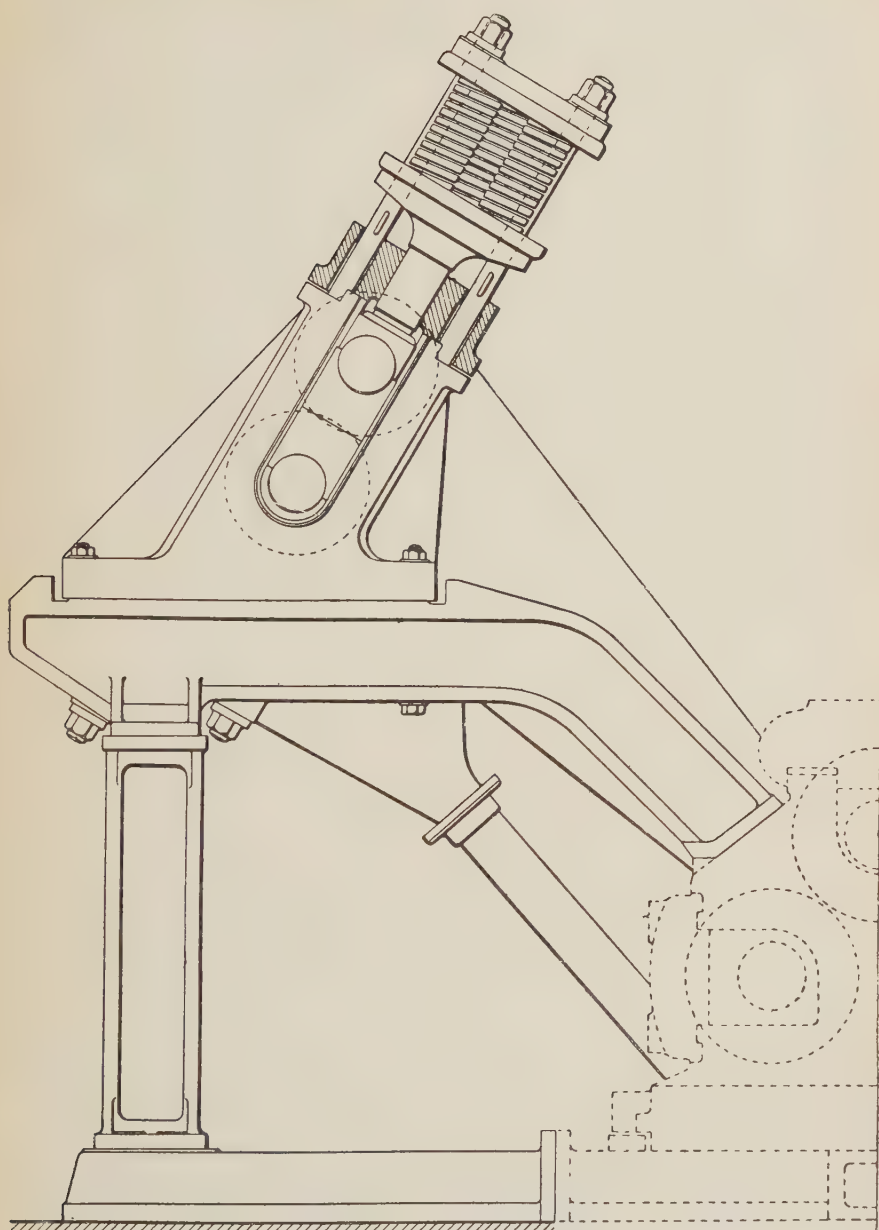
Fig. 119.

is here materially increased; on the other hand the curve of large rollers being flatter, cane is a longer time in contact and under pressure, and the rollers being further apart there is less risk of re-absorption, but at the same time, owing to the flatter curve, juice flows from the rollers less easily. A very favourite size in recently erected plants is a roller 78 in. × 36 in., experience having apparently shown that increase in diameter above this size is not attended by better results. When not increasing the diameter in proportion to length, the diameter of the gudgeons, and consequently their strength, does not increase in proportion to horse-power transmitted. A roller of such dimensions must essentially have its shaft made of the very best material; such a proportion with inferior material would only result in inferior work or in breakages.

Preparation of Cane for Milling.—In the great majority of modern mills the canes are subjected to a preparatory treatment before they enter the mill proper; the increased use of these appliances has been the outcome of various causes. In the first place it has been found that, by a preparatory treatment, the capacity of a milling plant is greatly increased, without any detriment to the quality of the work. Secondly, the use of unloading machines gives a mass of material much more uneven than that obtained by hand loading, so that the mill will often refuse the feed. The devices used in the preparatory treatment of the cane do not so much extract juice as that they level the mass of cane, and prepare it for the milling process proper. Thirdly, the replacement of the older varieties of cane by others, notably by certain seedlings, has resulted in the handling of a brittle material, which in many cases almost refuses to pass between the rollers of an ordinary mill without previous partial treatment.

The appliances used may be classed under three heads, crushers, shredders, and revolving knives. Of the first, the Krajewski crusher, *Figs. 119* and *120*, has been largely erected; it consists of two superimposed rollers; each roller is grooved at equal distance over its surface in such a way that the grooves form a succession of V shaped teeth, the teeth in one roller being opposite the recesses in the other. The rollers in this appliance can be placed at varying distances, so as either to crush the cane or even cut it into pieces of about four inches in length. The crusher is made to be worked off its own motor, or it may be driven off the main mill gearing. With mill rollers of 34 in. in diameter, it is customary to have the crusher rollers of about 26 in. in diameter, and to run them at a higher speed than the mill rollers, a peripheral speed in the crusher rollers of 28 to 30 ft. per minute being usual.
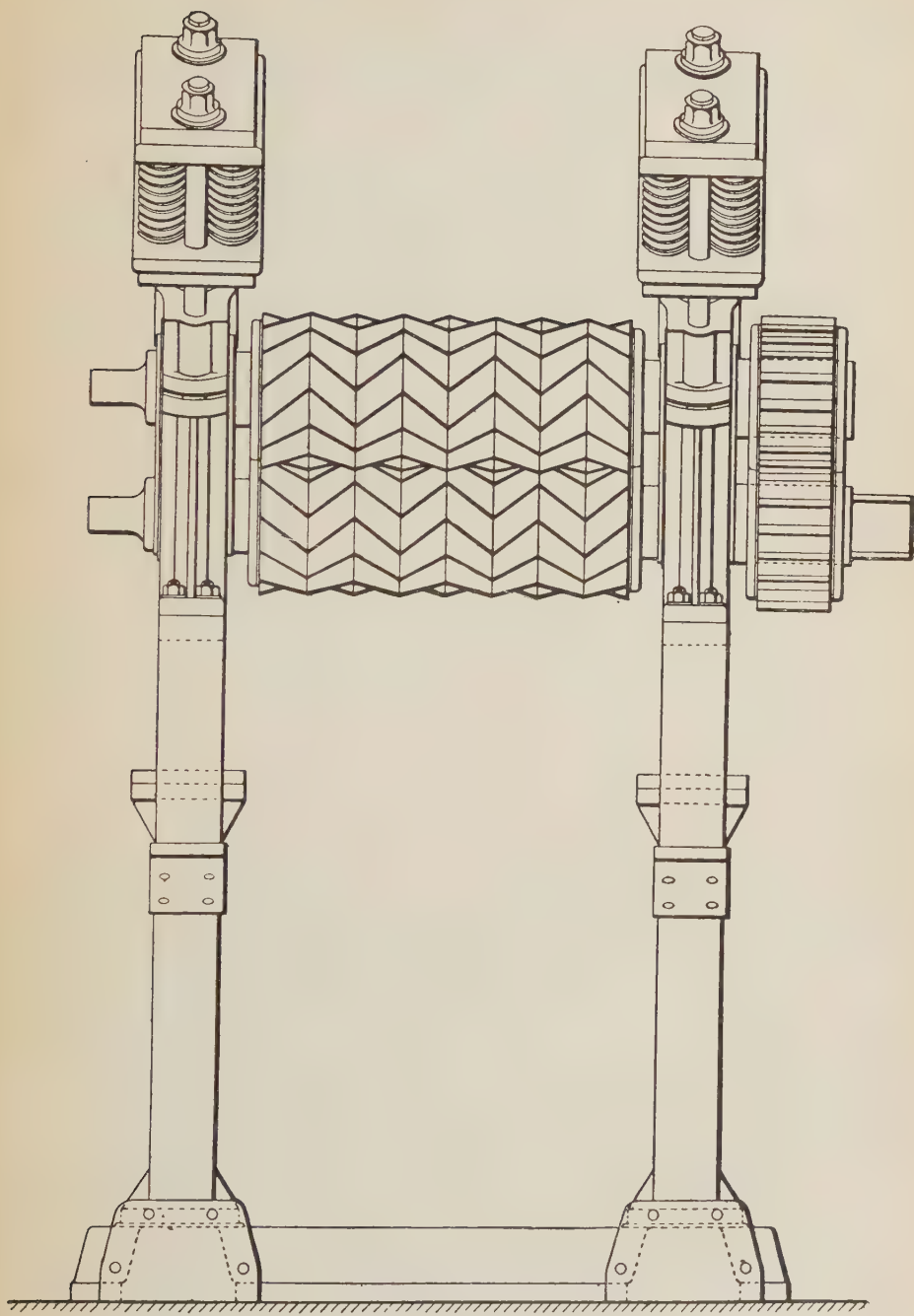
Fig. 120.

Cane shredders consist of two cylinders, on the surfaces of which are shrunk V shaped rings, as shown in *Fig. 121;* these cylinders are run at a high speed, the upper one making usually 250 revolutions per minute; the lower cylinder is geared to make twice as many revolutions as the upper one.
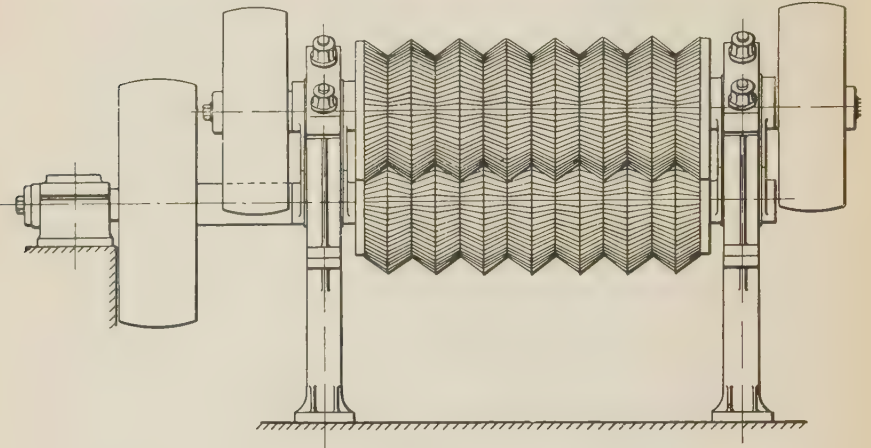

FIG. 121.

On passing between these cylinders the cane is subjected to torsion, and is so to speak '*shredded,*' but no juice is extracted, the treatment being entirely preparatory.
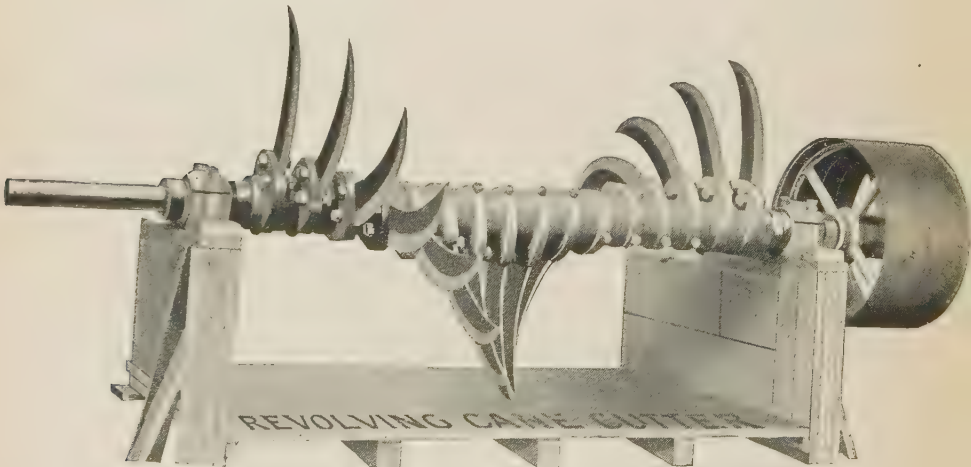

FIG. 122.

The general form of cane cutter is seen in *Fig. 122;* it consists of a cylinder on the periphery of which is arranged along a helix of slight slope a number of curved knives; these knives are spaced about 4 in. apart and are about 12 in. long; the cutter, which is run at about 300 revolutions per

minute, may be driven by its own motor, or very conveniently by belt gearing off the mill engine. The useful effect of this contrivance is very pronounced, and provided the knives are kept sharp but little power is used.

In some recent patterns the preparer is incorporated in the mill itself, and takes the form of a heavily indented top roller; three designs on the market are known as the Diamond, Excelsior, and Pelaez rollers; in the first-mentioned the surface of the roller consists of a number of prisms arranged at right angles to each other, so that the surface comprises a large number of L shaped units.

Of the earlier cane preparers, reference may be made to that of Faure, similar in principle to the shredder but with the bottom roll replaced by a fixed counter plate; to that of Bonnefin, consisting of a system of reciprocating saws, and to that of Mignon and Rouart in which the cane was fed into a cylinder wherein revolved a system of knives. This last device was based on the machines designed to pulp straw for paper making.
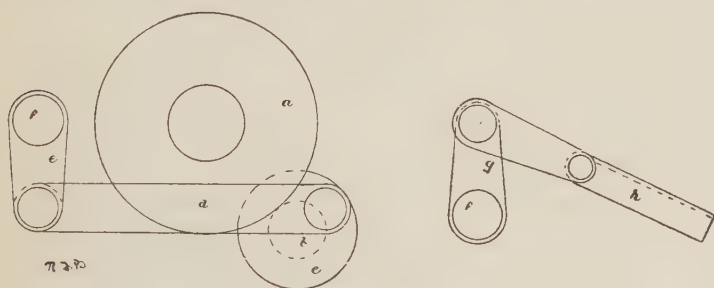
FIG. 123.

Forced Feed.—A diagram illustrative of the ' pusher' or forced feed is shown in *Fig. 123;* it is an apparatus designed automatically to force megass into a second or third mill and at the same time to ensure an even and regular feed. It consists essentially of a strong iron bar extending the length of the roller to which a to-and-fro motion is given by means of a spur and pinion and lever gear worked off the gearing of the cane engine; the rocking bar moves below the feeding table and above the front lower roller, and forces the megass into the mill by impact. In *Fig. 123 a* represents a spur wheel 6 ft. in diameter worked off the shaft of the second motion pinion of the cane engine; this wheel gears with a pinion *b* 10 in. in diameter; the pinion carries on one side a flange *c*, 20 in. in diameter; attached to the flange by means of a pin is a strong bar *d* which works the piece *e* to which is communicated a backwards and forwards movement in an arc of a circle; to *e* is attached a bar *f* running parallel to the rollers; *f* carries, placed at either end of the roller, pieces similar to *e* and to these is attached the pusher which forces the megass to the rollers. The pinion makes about 70 revolutions per minute, and this is consequently the number of strokes given by the pusher.

Pressure Regulators.—Mills of the pattern exemplified in *Fig.
101* may be referred to as rigid mills, that is to say, the distance the rollers
can be separated is limited by the setting and depends on the elasticity or
'give' of the mill; with such a pattern the pressure exerted on the layer of
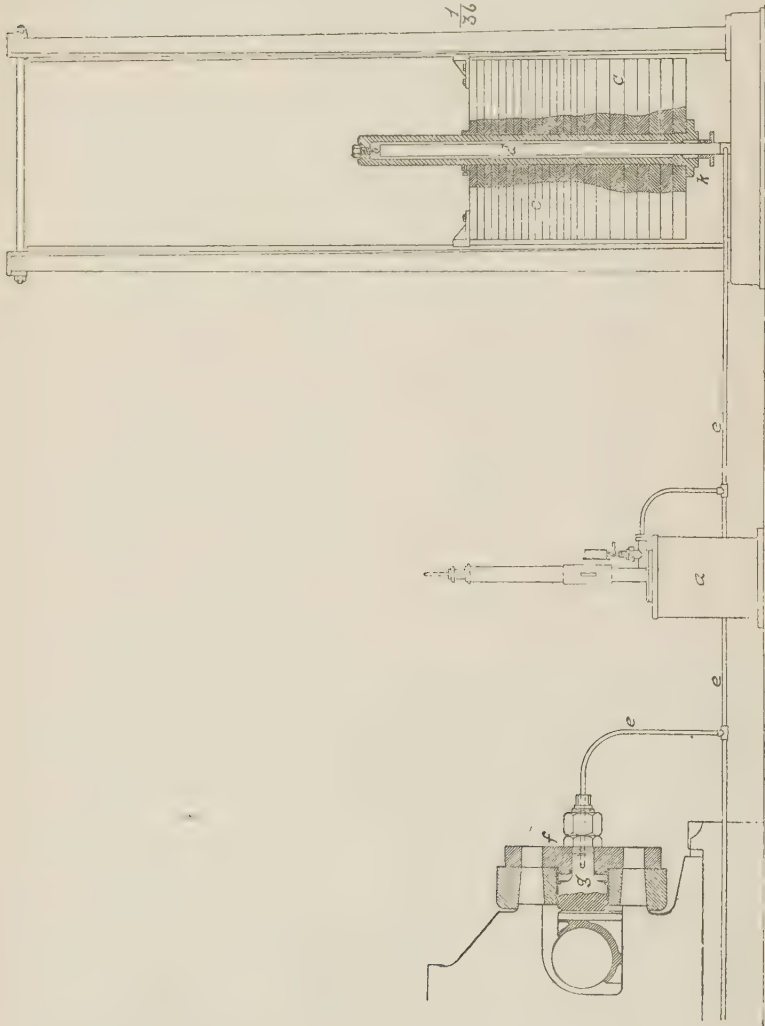megass is dependent on the quantity passing and any sudden strain, due either

FIG. 124.

to malice or accident, may result in the fracture of the mill. To overcome
this trouble all recent mills are provided with pressure regulating devices
which both maintain a constant pressure down to a certain minimum thinness
of feed and also allow a roller to lift in the case of the passage of any in-
compressible material such as of a piece of iron.

Patents for the hydraulic regulation of mills were granted to Stewart in England in 1871, and to MacDonald in the United States in 1872.

In *Fig. 124* is given a view of an hydraulic applied to the back roll of a mill and conforming to the arrangement generally followed by English engineering firms. The hydraulic pressure is applied by means of the ram g; if in any way the pressure becomes greater than that exercised by the ram, the latter gives way, allows the rollers to move and relieves the pressure.
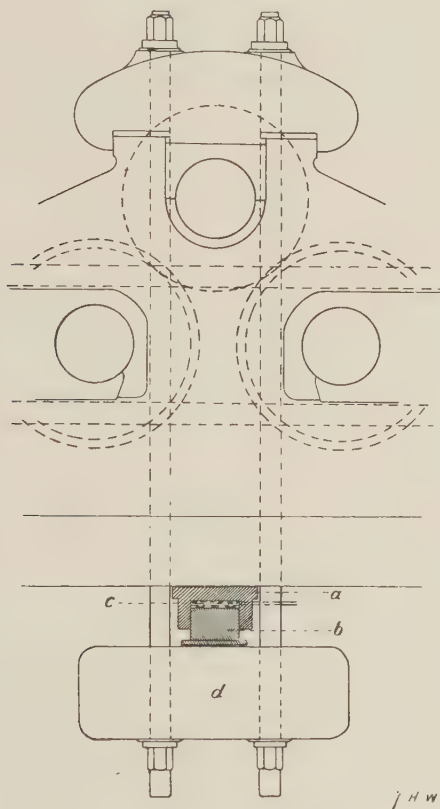
FIG. 125.

The plant consists of a small hand pump a, by means of which a fluid, generally oil, is pumped through the pipe $e\ e$ into the upright hollow rod d. Through d runs a channel about one quarter of an inch in diameter, communicating by a small aperture with the cylinder b; $c\ c$ are weights which rest on the flange k; as the pressure in the oil increases it raises these weights, and the pressure throughout the system is that due to the weights; the pipe e is continued through the cap f, the oil filling the hollow space enclosed between the cap f and the ram g. By a well-known principle of hydraulics if the area of the cross section of the ram is a and that of the fluid in the

accumulator is b the pressure required to move the ram is $\dfrac{ax}{b}$ where x is the sum total of the weights $c\,c$. When this system was first brought out the pressure applied was generally three tons per linear inch of roller, so that a roller sixty inches long had a pressure on the journals of 180 tons; to obtain this pressure the weights $c\,c$ would be about two tons, but now pressures of four, five, and even six tons per linear inch are not unusual.

In MacDonald's design (and this is the form usually adopted by United States engineering firms) the hydraulic is arranged beneath the mill, as shown diagrammatically in *Fig. 125*. The pot of the hydraulic is seen at a bearing directly on the sole plate of the mill; the oil chamber is seen at c and the ram at b; the holding down bolts are united by a yoke seen at d. The action of the two types is practically identical, a direct push in one case being replaced by a pull.
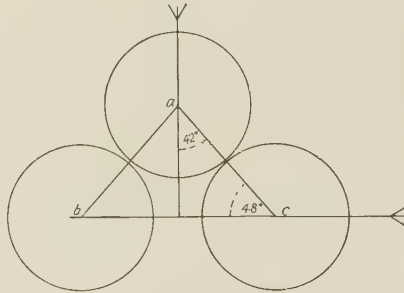
FIG. 126.

In the MacDonald type of hydraulic the tension is transmitted through the holding down bolts which may be as much as eight ft. long; any inaccuracy there is then magnified in the adjustment of the top cap, and in addition the unequal strains in the mill have a tendency to force the top cap out of the plumb, so that it may jamb against the side of the mill and prevent the hydraulic regulator acting; on the other hand, the design is readily accessible, and burst leathers can be replaced in a few minutes.

A source of trouble in all types of hydraulic is the unequal pressure on either side of the mill due to the thrust of the pinions; this may in part be compensated by making the area of the rams of different size, but in this case the allowance once made is fixed. A more elegant scheme entails the use of twin accumulators which may be loaded independently, and an equal travel on both sides of the mill obtained by trial and error.

The location of the hydraulic varies in practice; it is found applied to the top and to the back roll; in the former case it acts as a safety appliance equally to the front roller, and this is the more rational method to follow, as is also indicated by the following argument.

In *Fig 126* let *a*, *b*, and *c* represent the centres of the rollers of a three-roller mill; let the angle *bac* be, as is very usual, 84°; then the angles *abc* and *acb* are each 48°; let *w* represent a vertical pressure applied to the top roll; the line along which *w* acts will if produced bisect the vertical angle of the mill, so that the angle *cad* is 42°; the component of *w* along *ac*, that is along the line joining the centres of the top and back roller, is $W \cos 42°$, so that if *w* is 300 tons, the pressure on the megass is $300 \times \cdot 743$ or 222·9 tons. If now a horizontal pressure w^1 be applied to the back roller, the component
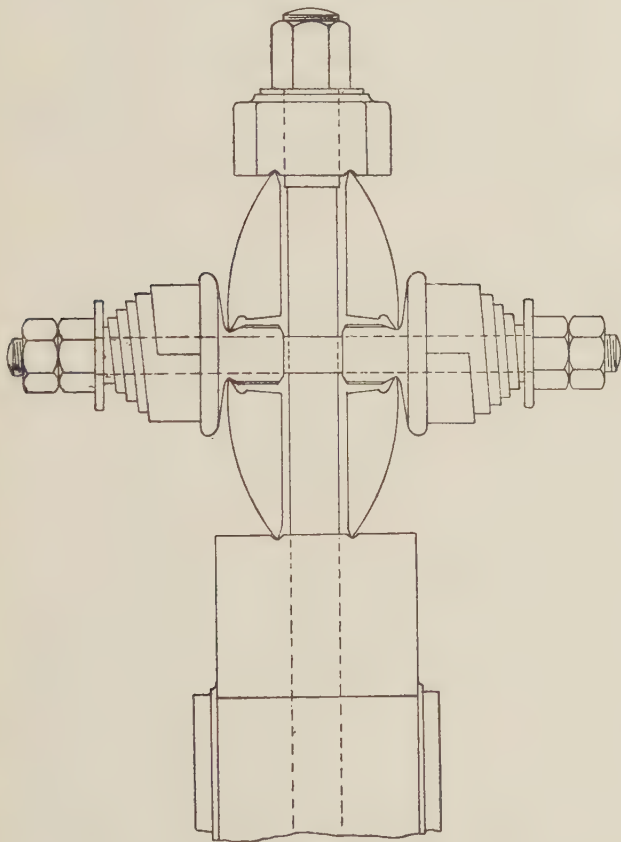
Fig. 127.

along *ac* is $w^1 \cos 48°$ and if w^1 be 300 tons, this quantity is $300 \times \cdot 669$ or 200·7 tons; hence with mills of the usual pattern a greater effective pressure is obtained when the hydraulic acts on the top roller.

The above argument shows too how with a small apex to the mill a greater effective pressure along the line joining the centres of the top and a lower roller is obtained; neglecting the difference in opening between top and front and top and back roller, this is given by $w \cos a_2$ where *w* is the vertical pressure on the top roller and *a* is the apex or verticle angle of the mill.

The toggle gear, *Fig. 127*, introduced and patented by the Mirrlees Watson Company, consists essentially of a combination of springs and knuckle or toggle levers, the tops of which press against the nuts of the cover bolts and the bottoms against the caps of the roller journals; under normal conditions the rollers rest on their bearings, but under heavy pressures they lift the caps which are controlled by the toggle gear until the upward pressure is balanced It is claimed for this contrivance that it is less expensive than a hydraulic regulator and that it performs the same duties; as in the hydraulic, the pressure can be regulated, in this case by adjusting the nuts that compress the springs.

Cane Carrier.—The apparatus used to transport cane from the cars to the mill is usually an endless belt slat conveyer, on the inside of which is arranged a link belt; gearing with this link belt are sprocket wheels driven by a chain drive from the mill; the driving sprocket can be thrown in or out of gear by a clutch; latterly cane carriers have been made independently driven by small engines.

Megass Carriers.—The intermediate carriers of the megass are usually slat carriers which leave much to be desired; belt conveyers have recently been used with much success in the Hawaiian Islands; in place of slat conveyers scraper carriers are sometimes seen, especially when the megass has to be elevated at a steep angle to the furnace room.

Strainers.—The removal of fine particles of fibre from the juice is best effected by arranging a long narrow tank parallel to the line of the mill into which the juice discharges through a perforated copper strainer; on this strainer runs an endless rubber-faced scraper which sweeps off the 'cush cush' and, after elevating it, discharges it into a screw conveyer running across the first mill; as this 'cush cush' contains much grit which injures the surface of the rollers the idea of passing it through a very small mill has been put into practice. Revolving strainers operated by the head of juice itself are also in use.

Calculation of necessary Opening between Rollers.*—

In order that the fibre, and the juice that accompanies it, may be passed out from between the rollers, it is necessary that there be a certain opening; the product of the opening into the area described by the revolution of the roller by a horizontal line on the circumference of the roller, that is to say, by the crushing surface, is a volume, which cannot be less than the combined volume of the emergent juice and fibre. As an example of the point made above let there be a mill with rollers 30 in. × 60 in.; then in each revolution of the roller the crushing surface is $\pi \times 30 \times 60$ sq. in. If the opening between the top and megass roller is $\frac{1}{32}$ in., then the volume described between the two rollers in one revolution, and which cannot be less than the combined volume

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* The sections immediately following apply primarily to rigid mills and are only applicable to hydraulic mills in a limited sense.

of the emergent juice and fibre, is $\pi \times 60 \times 30 \times \frac{1}{32}$ cubic inches. For lack of a better term this volume will be referred to in the sections immediately following as the *escribed volume*.

In the megass mills it is customary to set the top and back rollers practically metal to metal, and hence to allow the megass to pass, the rollers must become separated by a certain distance, which can be obtained by the calculation given below.

Let there be a mill of dimensions 60 in. × 30 in. running at the rate of two revolutions per minute; let 25 tons of cane carrying 12 per cent. of fibre be crushed per hour; let the megass as it leaves the mill contain 45 per cent. of fibre and 55 per cent. of juice; let the density of the juice be 1·07 and of the fibre be 1·35. Then in one hour there pass 3 tons of fibre and 3·66 tons of juice. The volume of the fibre passing per hour is

$$\frac{3 \times 2240}{62 \cdot 25 \times 1 \cdot 35} = 79 \cdot 96 \text{ c. ft., and that of the juice is}$$

$$\frac{3 \cdot 66 \times 2240}{62 \cdot 25 \times 1 \cdot 07} = 123 \cdot 19 \text{ c. ft.; and together } 203 \cdot 15 \text{ c. ft.}$$

To allow this quantity to pass, the escribed volume must not be less; the crushing surface per revolution is $\dfrac{\pi \times 30 \times 60}{144}$ sq. ft. $= 39 \cdot 28$ sq. ft.; so that at a speed of two revolutions per minute the minimum opening between the rollers is $\dfrac{203 \cdot 15}{39 \cdot 28 \times 120} = \cdot 043$ ft. $= \frac{33}{64}$ in.

If the rollers ran at 2·5 revolutions per minute, the minimum opening works out at $\frac{26}{64}$ in., so that with high speeds a smaller opening is necessary.

In actual practice the megass and top rollers are set metal to metal, and not to such relatively large distances as the above calculation implies; the volume necessary for the megass to pass is made up of the spaces formed by the grooving of the rollers, by roughness in their surface, and also by actual distortion and forcing apart of the rollers.

In the above conception it is necessary to distinguish between the actual and the apparent volume of the megass; the latter is the space occupied by the megass and includes the intercellular and interstitial spaces, and depends upon the structure and packing of the fibre; the former is the least volume into which the megass could be packed on the supposition that the space is filled wholly with megass.

Capacity of Mills.—It is easy to see that, provided all other conditions remain constant, the capacity of a mill is fixed by the escribed volume, and hence if two mills of different size be run at the same peripheral speed, that the capacity is fixed by the crushing surface. There are, however, many factors that do not remain constant, and which can be varied at will, so that so simple a relation does not hold. As a matter of empirical observation

the writer has noticed that the capacity of mills otherwise similar is proportional to the cubic contents of one roller, and that, in the case of a nine-roller mill and crusher, the following simple relation holds. *The capacity in short tons of cane per hour is equal to the cubic contents in feet of one roller.*

Three sizes of rollers often found are 30 in. × 60 in., 32 in. × 66 in., 34 in. × 78 in.; the cubic contents of these rollers are 24·5 c. ft., 30·7 c. ft., and 41·4 c. ft., and these figures represent very closely the amount of cane treated by mills of this size in combination with a cane preparer.

The addition of a fourth mill is found in practice to add at least 25 per cent. to the capacity without detriment to the quality of the work, and the absence of a cane preparer to take away about 10 per cent.
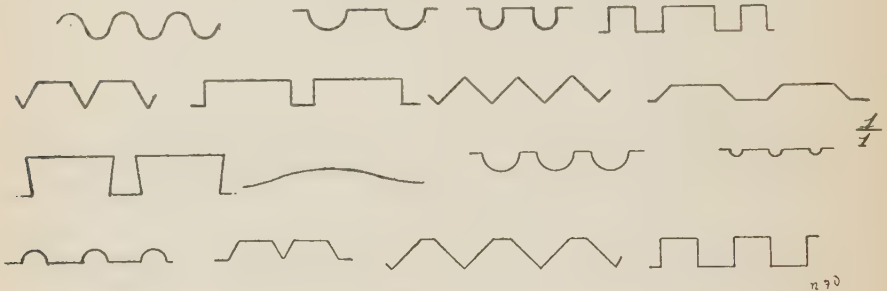
Fig. 128.

The capacity of an existing plant can be varied within certain limits without detriment to the quality of the work by regulation of the escribed volume; this can be controlled by increasing the peripheral speed of the rollers or by increasing the opening between them ; if the capacity of a mill is to be increased on these lines, it is of course necessary that there be sufficient engine power available to treat the increased quantity of cane. The capacity of a mill is also affected by other causes that cannot well be treated on paper; some of these are :—

1. The nature of the material treated, including such points as the hardness, brittleness, and fibre content of the canes.

2. The ' slip ' of the mill.

3. The roughness of the rollers ; it is a matter of experience that the capacity of a mill is increased with rough surfaces, and rollers are now made with a special coarse-grained surface; grooving the rollers has a similar effect. Forms of grooves as found in practice are shown in *Fig. 128.*

5. The setting of the trash bar.

6. The regularity and evenness of the feed.

Surface Speed of Rollers as affecting Expression of Juice.—A number of years ago 15 to 16 feet per minute was a usual surface

speed for mill rollers. The more recent tendency is to design the gearing so that the mills run at a speed up to 25 feet per minute. It has also been the custom to so arrange the gearing that there is an increase in the surface speed from mill to mill; a thinner blanket of megass is thus obtained, which it is claimed parts with its juice more readily than the thicker blanket obtained if all the mills run at the same speed.

By a reversal of the calculation given in the preceding section, it follows that, if the volume escribed by the revolution of the rollers is 203·15 cubic feet, the megass consists of 79·96 cubic feet of fibre and 123·19 cubic feet of juice; let this volume of megass which is derived from 25 tons of cane be passed with the rollers making 2·5 revolutions per minute; let the speed be now reduced to 2 revolutions per minute; then the volume now escribed by the rollers in one minute becomes, if the setting remains unaltered, 182·52 cubic feet: since the volume occupied by the fibre is the same in both cases (79·96 c. ft.), there is with the slower speed a volume of (182·52−79·96) or 102·56 c. ft. remaining for the juice; taking this as of density 1·07 as before, the composition of the megass now works out at 50·4 per cent. juice and 49·6 per cent. fibre, as compared with 55 per cent. juice and 45 per cent. fibre when the speed was 2·5 revolutions per minute. In the opinion of the writer, this argument points to the obtaining of better results with small speeds; the reasoning is not free from objection since, for example, with the thicker blanket there will be a greater tendency to force the rollers apart and thus to increase the escribed volume.

Quantity of Fibre in Cane as affecting Composition of Megass.—The conception of the escribed volume can be used to show how the percentage of water and of fibre in a megass will vary with the initial composition of the cane. In the example already taken it was shown that, with an escribed volume of 203·15 c. ft., canes containing 12 per cent. of fibre afford a megass of composition fibre 45 per cent. and juice 55 per cent.; let canes containing 10 per cent. of fibre be now milled, the setting and speed of the mills and the weight of cane remaining unchanged; the amount of fibre now passing in one hour is 2·5 tons and this quantity will occupy 66·63 c. ft., so that there remains 203·15−66·63=136·52 c. ft. to be occupied by the juice; this volume of juice, if of density 1·07, will weigh 4·06 tons, and the total weight of megass will be 6·56 tons, so that the percentages of fibre and juice are 38·1 and 61·9 respectively.

It follows then, that with a fall in the fibre content of the cane the escribed volume must be decreased to obtain the same results as with the larger quantity of fibre; this effect can be obtained by running at a slower speed or by decreasing the distance between the rollers; conversely, megass of the same composition will result by increasing the quantity of cane milled.

Saturation—By this expression is meant any process where water is added to the dry crushed canes, which are then recrushed; a diluted juice containing a proportion of the juice left after the dry crushing is then obtained; two methods of applying the water may be distinguished; in one the water is allowed to impinge directly on the megass, and in the other the diluted juice is returned to a bath, through which the megass is drawn. In Mauritius the writer observed that the term '*imbibition*' was applied to the former, and '*maceration*' to the latter process; in what follows these terms are adopted.

The earliest mention of a saturation process is due to Wray; he describes a plant at work in Province Wellesley in 1848; it consisted of a three-roller mill as the dry crusher, followed by a two-roller mill as the recrusher; the megass was carried from the first mill to the second by a travelling band, on which fell a rain of hot water from an overhead tank; the surplus water that drained off was sent to the distillery.

In order to obtain a premium of 100,000 francs, Duchaissing introduced a saturation process into the island of Guadeloupe; the apparatus was very similar to the one described by Wray; the two mills were placed eighteen feet apart, and between them ran a travelling band, the underside of which dipped into a tank of hot water while another tank placed above distributed a rain of hot water over the megass. Over the travelling band was arranged a series of beaters. The juice from the two mills could be collected separately, and if the second mill juice was greatly diluted it was returned to the megass from the first mill.

Russel and Risien's scheme introduced into Demerara about the same time was somewhat different; the mills were placed about thirty feet apart and connected as before by a travelling band. This band ran in a closed chamber of the form of a shoot; a system of perforated piping ran along the bottom and top of the shoot by means of which water or steam was forced upon the megass; means were also here provided for treating the first and second mill juice separately.

Rousselot, who also reduced the cane mill to its present form, patented and introduced into Martinique a system of saturation; his process was essentially one of imbibition. In the Hawaiian Islands saturation was introduced by Alexander Young who sold mills on a system of payment by results.

All these schemes were incepted in the seventies.

Maceration.—In *Fig. 129*, is shown a train of two mills separated by a macerating bath. Several ways of operating this process are to be met with. With a train of three mills, imbibition may be practised between the second and third mills and the third mill juice may be pumped into the bath between the first and second mills; in any case the returned juice enters the bath at the end next a later mill and flows in a direction opposite to that in
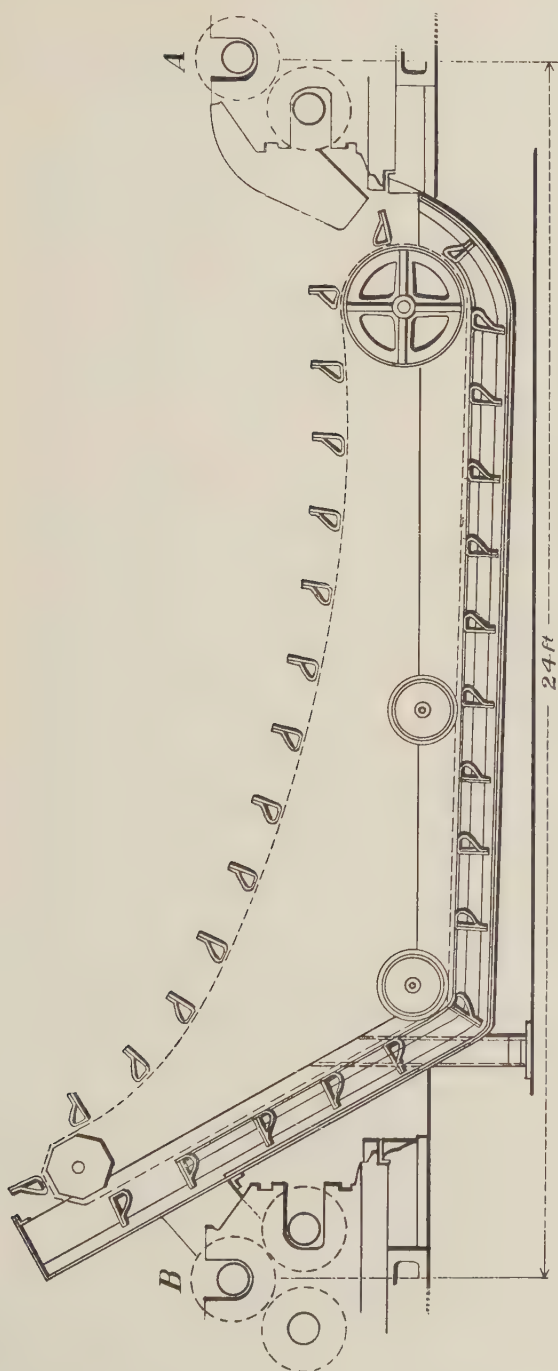
FIG. 129.

24 ft

203

which the megass travels, finally overflowing at the end next the earlier mill whence it passes to the boiling house.

Macerating baths may also be arranged between the last two mills of a train, say, of three mills; in this arrangement the expressed juice from the last mill is returned to the bath in front of the last mill; the added water enters the bath immediately behind the returned juice. The flow of the juice is as described above, and on leaving the bath it is pumped to the bath between the first and second mills, and on overflowing from this bath passes to the boiling house, together with the juices expressed from the first and second mills.

In another scheme, the juice expressed from the second mill is also returned to the bath between the first and second mills along with the third mill juice, and finally added water may be used in this bath as described above, the juices from the second and third mills passing separately to the boiling house.

The juice in the baths is removed before the mills stop, by ceasing to return the juices for about 30 minutes before closing down; the megass, in its passage through the bath, then mops up the juice present at the time that the return of juices is stopped.

Comparison of Imbibition and Maceration.—In all the recently erected mills in the Hawaiian Islands an imbibition process is used; the mills are placed close together, being driven through the train of gearing shown in *Fig. 112* by one engine. With this arrangement there is no room for a macerating bath. The majority of plants recently erected in other districts also conform to this pattern; macerating baths are to be found in Mauritius, in Fiji and in Australia, but the process is not by any means as common as imbibition. The writer has always been an upholder of the maceration process, and formed this opinion from the results obtained when once in a position to make comparative tests. In view, however, of the balance of opinion in favour of imbibition, he is unwilling to dogmatize on the subject.

The benefit of maceration is most pronounced with the imperfectly crushed megass coming from an earlier mill: generally the rupture of the cane is at this stage so imperfect that the water added as imbibition is but little absorbed.

To a certain extent the preference of engineers for a compact train of gearing, and considerations of first cost, account for the more extended use of imbibition; where the mills have each their own engine, as is the case in plants erected piecemeal, this objection to maceration does not hold.

General Principles in Saturation.—In conducting saturation processes the following points are of importance :—

1.   The water must be evenly distributed over the megass.

2.   The water must penetrate into the megass; to this end it must be under a considerable head, so as to reach the lower layers; a pipe led under the blanket

of megass may be used in addition to the one throwing water on to the upper surface.*

3.　To enable the megass to absorb water readily, it must be finely crushed; generally first crushing megass is not fine enough to readily absorb water.

4.　A greater recovery is obtained when the diluent is used in two portions; this is sometimes referred to as double maceration.

5.　As the mixture of juice and water is not instantaneous, as much time as possible should elapse between two successive crushings.

6.　It is not economical to allow badly crushed megass to pass the first mill on the supposition that the subsequent wet crushing makes up for the loss; it does not.

7.　The whole duty of maceration depends on the completeness of the admixture.

Source of Water for Saturation.—The water which is used in maceration is conveniently derived from the condensed water in juice heaters, eliminators, or effects.　In the first two, the water being under pressure no pump is required.　If the multiple effect water be used, it is convenient to pump it to elevated tanks, and thence to allow it to gravitate to the mills.　By this arrangement the water can be measured, a point of considerable importance in technical control.　Very often the maceration water is derived from the hot water supply for the boilers, a pipe being led from the boiler feed pump to the mills.

Algebraical Treatment of the Extraction of Juice from Canes.—Let f and m denote the fibre per unit weight of cane and of megass; then the weight of megass per unit weight of cane is $\frac{f}{m}$ and the weight of juice expressed is $\frac{m-f}{m}$; the weight of juice per unit weight of cane is $1-f$, so that the juice extracted per unit weight of juice in the cane is $\frac{m-f}{m(1-f)}$. The weight of juice remaining in the megass is $\frac{f(1-m)}{m}$ and the juice lost in the megass per unit weight of juice in cane is $\frac{1-m)}{(m\,1-f)}$.　As the fibre in the cane increases, that in the megass remaining constant, the weight of juice extracted by the mills decreases; in the annexed table are given values of the expression $\frac{m-f}{m}$ for values of f 8 to 16 and of m 35 to 45; that is to say, the weight of juice obtained per 100 cane, when the latter contains from 8 per cent. to 16 per cent. of fibre, and when the megass contains from 35 per cent. to 45 per cent.

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* The distribution of the water by means of injectors as described by L. Pellet at the 1909 Congress of Applied Chemistry would appear to fulfil these requirements; their use would in any case be superior to a perforated pipe or to a distributing trough.

FIBRE IN CANE.

Fibre in Megass.	8	8·5	9	9·5	10	10·5	11	11·5	12	12·5	13	13·5	14	14·5	15	15·5	16
35	77·14	75·72	74·29	72·86	71·43	70·00	68·58	67·15	65·72	64·29	62·26	61·44	60·00	58·58	57·15	55·72	54·29
36	77·78	76·39	75·00	73·61	72·22	70·83	69·45	68·05	66·67	65·28	63·89	62·50	61·11	59·72	58·33	56·94	55·56
37	78·38	77·03	75·68	74·33	72·96	71·62	70·27	68·92	67·57	66·22	64·87	63·52	62·17	60·82	59·46	58·11	56·76
38	78·95	77·63	76·32	75·00	73·68	72·37	71·05	69·74	68·42	67·11	65·79	64·47	63·16	62·82	60·33	59·21	57·89
39	79·49	78·21	76·92	75·63	74·35	73·07	71·79	70·50	69·22	67·94	66·66	65·38	64·09	62·81	61·53	60·25	58·97
40	80·00	78·75	77·50	76·25	75·00	73·75	72·50	71·25	70·00	68·75	67·50	66·25	65·00	63·75	62·50	61·25	60·00
41	80·49	79·27	78·05	76·87	75·61	74·39	73·17	71·95	70·73	69·54	68·30	67·08	65·86	64·64	63·42	62·20	60·98
42	80·95	79·76	78·57	77·38	76·19	75·00	73·81	72·62	71·43	70·24	69·05	67·89	66·70	65·51	64·32	63·13	62·94
43	81·40	80·24	79·07	77·91	76·75	75·57	74·41	73·25	72·09	70·94	69·76	68·59	67·45	66·28	65·12	63·96	62·89
44	81·88	80·68	79·55	78·41	77·27	76·14	75·01	73·87	72·73	71·59	70·46	69·32	68·19	67·05	65·91	64·78	63·64
45	82·22	81·11	80·00	78·99	77·67	76·56	75·44	74·33	73·22	72·11	71·00	69·99	68·88	67·77	66·66	65·55	64·44

By dividing the weight of juice obtained by the weight of juice in the cane, *i.e.*, by *1—f*, the sugar extracted per unit of sugar in the cane would be obtained, provided the juice were of uniform composition.

As was originally pointed out by the late Mr. Francis, formerly Government analyst in British Guiana, the residual juice in megass is of considerably less sugar value than that first expressed by the mills. The following figures obtained by the writer using a small hand mill will give some idea of the relationship existing between expressed and residual juice :—

Percentage of juice expressed.		Sugar per cent. in expressed juice.		Sugar per cent. in residual juice.		One part residual equal to parts of expressed juice.
74·77	..	17·34	..	15·36	.	·885
73·69	..	17·47	..	15·20	..	·870
70·46	..	17·31	..	14·35	..	·829
65·75	..	16·43	..	12·50	.	·762
68·14	..	16·49	.	14·63	..	·887
70·63	..	16·11	..	12·74	..	·791
66·04	..	16·69	..	13·73	..	·824
70·41	..	16·07	.	13·17	..	·819
75 93	..	14·86	..	12·38	..	·833
73·82	..	13·99	..	10·73	..	·767
72·08	..	13·44	..	11·46	..	·853
69·54	..	12·88	..	10·97	..	·852
69·38	..	17·75	..	14·02		·789

Mean ·830

Let the sugar value of the expressed juice be represented by unity, and the sugar value of the residual juice by a; then the sugar value of all the juice in the cane is given by the expression

$$\frac{m - f}{m} + \frac{a f (1 - m)}{m} = \frac{m + af - f - afm}{m},$$

and the extraction will be given by the formula

$$\frac{m - f}{m} \div \frac{m + af - f - afm}{m} = \frac{m - f}{m + af - f - afm}.$$

If to a be given the value ·85, it will be found that the extraction corresponding to the weight of juice expressed is about 3 per cent. higher than that given by the formula $\frac{m - f}{m(1 - f)}$ = extraction.

In the table below is calculated the extraction obtained when canes containing from 10 per cent. to 14·5 per cent. of fibre are crushed to a megass containing 45 per cent. of fibre, using as a formula the expression,

$$extraction = \frac{1·03 \ (m - f)}{m(1 - f)} :—$$

Fibre in cane.		Extraction.		Fibre in cane.		Extraction.
10·0	..	89·0	..	12·5	..	85·0
10·5	..	88·2	..	13·0	..	84·2
11·0	..	87·4	..	13·5	..	83·3
11·5	..	86·6	..	14·0	..	82·5
12·0	..	85·8	..	14·5	..	81·7

Saturation Processes.—Let canes containing f fibre be crushed till the megass contains m fibre, and to the resulting $\frac{f}{m}$ megass let w water be added, the water mixing completely with the residual juice in the megass. The weight of the megass and added water now is $\frac{f}{m} + w = \frac{f + w\,m}{m}$, and the residual juice in the megass being $\frac{f\,(1 - m)}{m}$, the weight of the diluted juice is $\frac{f\,(1 - m)}{m} + w = \frac{f + w\,m - f\,m}{m}$. If this saturated megass be crushed until it again contains m fibre per unit weight of megass, the weight of diluted juice obtained is $w \div \frac{f + w\,m - f\,m}{m} = \frac{w\,m}{f + w\,m - f\,m}$. If instead of crushing the saturated megass to m fibre, it be crushed to m^1 then the proportion of juice obtained of that originally present is $\frac{m^1\,(f + w\,m) - f\,m}{m^1\,(f + w\,m) - f\,m}$.

The use of this method of calculation permits the different schemes for applying water in saturation processes to be critically examined.

Single Saturation.—By this term is meant a process where the canes, after dry crushing, are saturated once with water and again crushed. In the annexed table is calculated, on the lines developed above, the extraction due to saturation, and the total extraction on the understanding that the megass contains 45 per cent. fibre in the dry crushing, and 50 per cent. in the saturated crushing.

The added water is assumed to mix completely with the residual juice and the latter is taken as having a sugar value equal to ·85 of the juice obtained in the dry crushing.

It follows as a result of the equation, and as can be seen from inspection of the table on page 209, that as the quantity of added water increases, the proportionate quantity of sugar obtained due to saturation rapidly decreases; further, as the proportion of fibre in the cane increases, the part extracted due to saturation increases also, so that with high fibre in cane, it is of greater importance to carefully oversee the admixture of the added water, and to control as far as possible the fibre in the raw material entering the mill.

Double Saturation.—By this term is meant a process in which the water is added in two portions, in the case of a nine-roller mill partly after the first, and partly after the second mill; in general such a scheme is not attended with very material benefit with the nine-roller mill, since the megass coming from the first mill is not in general sufficiently well crushed to absorb the added water. In a twelve-roller mill, however, material benefit follows by adding the water in part behind the second, and in part behind the third mill. In the case of a cane containing 10 per cent. of fibre dry crushed to 45 per cent. of fibre, and then after the addition of 10 per cent. of water with complete admixture, and crushing to 50 per cent. of fibre, an extraction of

Table showing the maximum extraction to be obtained with single maceration, with complete admixture of added water; dry crushed megass containing 45 per cent. fibre, and saturated crushed megass containing 50 per cent. fibre.

Extraction due to saturation in upper, and total extraction in lower, line.

Fibre per 100 cane.	Water added per 100 cane.								
	10	15	20	25	30	35	40	45	50
10·	6·04	6·95	7·58	8·04	8·39	8·66	8·88	9·07	9·22
	95·05	95·96	96·59	97·05	97·40	97·67	97·89	98·08	98·23
10·5	6·36	7·33	8·00	8·50	8·88	9·18	9·41	9·61	9·80
	94·59	95·56	96·23	96·73	97·11	97·41	97·64	97·84	98·03
11·	6·68	7·71	8·44	8·98	9·39	9·72	9·99	10·21	10·40
	94·10	95·13	95·86	96·40	96·81	97·14	97·41	97·63	97·80
11·5	6·97	8·07	8·85	9·43	9·87	10·23	10·51	10·76	10·96
	93·61	94·71	95·49	96·07	96·51	96·87	97·15	97·40	97·60
12·	7·28	8·44	9·27	9·89	10·37	10·75	11·07	11·33	11·55
	93·10	94·26	95·09	95·71	96·19	96·57	96·89	97·15	97·37
12·5	7·58	8·81	9·68	10·34	10·86	11·27	11·61	11·89	12·13
	92·58	93·81	94·68	95·34	95·86	96·27	96·61	96·89	97·13
13·	7·87	9·17	10·09	10·80	11·35	11·70	12·15	12·45	12·71
	92·04	93·34	94·26	94·97	95·52	95·96	96·32	96·62	96·88
13·5	8·17	9·52	10·50	11·24	11·82	12·29	12·68	13·00	13·27
	91·51	92·86	93·84	94·58	95·16	95·63	96·02	96·34	96·61
14·	8·46	9·87	10·90	11·68	12·30	12·80	13·21	13·55	13·85
	90·96	92·37	93·40	94·18	94·80	95·30	95·71	96·05	96·35

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95·0 per cent. (see previous Table) is obtained, leaving 5 per cent. in the megass ; if, to this megass 10 per cent. water on weight of cane is added with complete admixture, and the megass be again crushed to 50 per cent. of fibre, of the sugar remaining $\dfrac{wm}{f + wm - fm}$ part is obtained; substituting for f ·10, for m ·50 and for w ·10 this expression reduces to ·5 ; hence of the five parts of sugar remaining in the megass 2·5 are extracted, and the total extraction becomes 95·0 + 2·5 = 97·5, compared with the 96·6 obtained when the whole twenty parts of water were added in one portion. This possibility of adding the water in two equally effective portions is a strong argument in favour of the twelve-roller mill. In the annexed table is calculated the maximum extraction to be obtained in a twelve-roller mill, with double saturation and complete admixture of the added water, which is added in two equal portions behind the second and third mills. The dry crushed megass is taken as having 45 per cent., and the saturated crushed megass 50 per cent. of fibre. The result of the calculation shows an advantage in favour of double maceration of the order of 1 per cent.

Table showing the maximum extraction to be obtained with double maceration with complete admixture of added water ; dry crushed bagasse containing 45 per cent. fibre and saturated crushed bagasse containing 50 per cent. fibre.

Extraction due to saturation in upper, and total extraction in lower, line.

Fibre per 100 cane.	Water added per 100 cane.			
	20	30	40	50
10·	8·51	9·37	9·85	10·15
	97·52	98·38	98·86	99·16
10·5	9·00	9·94	10·47	10·80
	97·23	98·17	98·70	99·03
11·	9·49	10·52	11·11	11·48
	96·91	97·94	98·53	98·90
11·5	9·94	11·06	11·71	12·12
	96·58	97·70	98·35	98·76
12·	10·42	11·63	12·34	12·79
	96·24	97·45	98·16	98·61
12·5	10·88	12·19	12·95	13·45
	95·88	97·19	97·95	98·45
13·	11·33	12·74	13·57	14·11
	95·50	96·91	97·74	98·28
13·5	11·78	13·28	14·18	14·66
	95·12	96·62	97·52	98·00
14·	12·23	13·82	14·78	15·41
	94·73	96·32	97·28	97·91

Compound Saturation.—The highest possible efficiency of the added water is obtained, when the diluted juice from a later mill is used as a saturating agent on the megass coming from a previous one; an algebraical expression showing the effect of this procedure is not easy to obtain, and when obtained is not elegant; the effect of this way of working is best shown by a worked out example :—

Let canes containing 12 per cent. of fibre be dry crushed to 45 per cent. of fibre in the first nine rollers of a twelve-roller mill; let water 30 per cent. on weight of cane be now added to the megass with complete admixture, and let the saturated megass be crushed to 50 per cent. of fibre; then applying the equations established above, in the dry crushing an extraction of 85·8 per cent. is obtained, leaving 14·2 per cent. in the megass; of this 14·2 per cent. the saturated crushing will in the fourth mill extract 10·4 per cent., so that the total extraction is 85·8 + 10·4 = 96·2 per cent. Let this 10·4 per cent. contained in the diluted juice be returned to the dry crushed megass; the immediate effect of this is to reduce the extraction due to dry crushing from 85·8 to 85·8 − 10·4 = 75·4 leaving 24·6 in the megass; let this megass be crushed to 50 per cent. of fibre; then of the sugar contained in this megass 73·1 per cent. is obtained; ·731 × 24·6 = 17·9, so that the extraction at this stage is 75·4 + 17·9 = 93·3 and 6·7 is left in the megass, which is now to be saturated with water 30 per cent. on cane, and crushed to 50 per cent. of fibre; of the whole amount of sugar now left in the megass 55·5 per cent. is now extracted; ·555 × 6·7 = 3·7, so that the total extraction is 93·3 + 3·7 = 97·0. Now let the 3·7 per cent. of sugar contained in the fourth mill juice be returned to the dry crushed megass; the extraction due to dry crushing is now reduced to 85·8 − 3·7 = 82·1, leaving 17·9 in the megass; as before 73·1 per cent. of this is extracted in the third mill; ·731 × 17·9 = 13·1, and the extraction at this stage is 82·1 + 13·1 = 95·2, leaving 4·8 in the megass; again let water 30 per cent. on canes be added and 55·5 per cent. of this is obtained in the fourth mill; ·555 × 4·8 = 2·7, so that the total extraction is 95·2 + 2·7 = 97·9.

Proceeding in this way and calculating the extraction by a series of steps, it is found that each successive addition to the extraction becomes smaller and smaller, until no appreciable difference is found. In the present case, the limiting value is found to be practically 98·6. If the water had been added in two portions, and the diluted juice had not been returned, the extraction found on similar lines would have been 97·4 per cent.

For purposes of comparison comparative data of the results to be obtained by different methods of adding the water are given below :—

If canes with 12 per cent. fibre with added water 20 per cent. on canes give in a nine-roller mill with single saturation an extraction of .. ..   96·2

The same canes with double saturation in a twelve-roller
    mill will give an extraction of   .. ..   97·4
And with compound saturation in a twelve-roller mill will
    give an extraction of .. ..   98·0

The Effect of an inferior Dry Crushing.

—Instead of taking 45 per cent. of fibre in the dry crushed megass, let the percentage of fibre be 40 per cent. Then if the canes contain 12 per cent. of fibre, the extraction due to dry crushing is 81·93 per cent., leaving 18·07 per cent. in the megass; let this megass after the addition of water be crushed to 50 per cent. of fibre; below is calculated what will be the extraction with single maceration after the addition of water 10 per cent., 20 per cent., &c., on cane, and for the purpose of comparison the figures already obtained when the dry crushed megass contains 45 per cent. of fibre are added.

	Water added per 100 cane.				
	10	20	30	40	50
40 per cent. of fibre in dry crushed megass	92·26	94·29	95·48	96·26	96·80
45 per cent. of fibre in dry crushed megass	93·10	95·09	96·19	96·89	97·37

The advantage in favour of the more effective dry crushing is in reality greater than is shown in the above calculation; complete admixture is in both cases assumed; in practice we do not obtain complete admixture, but the admixture will be the less imperfect the more the megass is disintegrated; that is to say, when the fibre content is higher.

The Economic Limit of Saturation.

—It is well known that with each increment of extraction the purity and the amount of available sugar per 100 sugar extracted also falls; if with an extraction a the proportion of available sugar is x, and with an extraction of $a + d$ the proportion of available sugar is $x - e$, it is easy to conceive a state where $a\,x$ is greater than $(a + d)(x - e)$ and where $(\pounds\,a\,x - \text{expenses})$ is greater than $[\pounds\,(a + d)(x - e) - \text{expenses}.]$ In order to put this conception to the test the writer crushed canes with the addition of water in a hand mill till over 98 per cent. of the sugar was obtained; in all, eight fractions of juice were obtained, each one being measured and analysed separately; there was thus obtained the extraction at eight points together with the available sugar; the available sugar was calculated from the $\dfrac{s\,(j - m)}{j\,(s - m)}$ formula developed in *Chapter XXV.*, giving to s and m the values 97·5 and 45·0.

The results of the experiments are as below :—

Fraction.	Weight per cent. Cane.	Total Solids per cent.	Sucrose per cent.	Purity.	Value of $\dfrac{s\,(j-m)}{j\,(s-m)} \times 100$
1	34·7	19·10	17·71	92·7	95·5
2	16·0	19·20	17·23	89·7	92·6
3	13·0	19·04	16·70	87·7	90 4
4	9·8	13·22	11·64	88·0	90·7
5	11·3	7·22	6·01	83·2	85·3
6	10·0	5·50	4·44	80·8	82·3
7	12·0	4·00	3·16	79·0	79·9
8	11·6	2·86	2·17	75·9	75·7
Megass	28·0	2·05	1·33	65·0	57·3

Referring to the above table which represents the mean result of a series of experiments, the decreasing purity of each successive fraction of juice is well shown, except at the fourth fraction where an increase over the third is noticed. This increase, obtained in all the experiments, is not due to accident or error. The third fraction was obtained under very heavy pressure, and probably contained much rind tissue juice. The fourth fraction was the first obtained by adding water to the megass, and probably consisted largely of pith tissue juice (which had remained unexpressed), to the exclusion of rind tissue juice as the rind had not yet been sufficiently broken up to take up its proportion of water.

The following table gives the sucrose obtained in each fraction per 100 sucrose in cane, and in the last column is contained the amount of available sugar per 100 sucrose in cane.

Fraction.	Sucrose obtained per 100 Sucrose in cane.	Purity.	Value of $\dfrac{s\,(j-m)}{j\,(s-m)} \times 100$	Product of Cols. 2 and 4 ÷ 100
1	43·2	92·7	95·5	41·3
2	19·1	89·7	92·5	17·8
3	15·1	87·7	90·4	13·8
4	8·0	88·0	90·7	7·3
5	4·7	83·2	85·3	4·0
6	3·0	80·8	82·3	2·5
7	2·6	79·0	79·9	2·2
8	1·7	75·9	75·7	1·3
Megass	2·6	69·0	57·3	1·5

The third table gives the extraction at any point, the purity and proportion of available sugar, and the available extraction, i.e., the available sugar per 100 available sugar in the cane.

Extraction.	Purity.	Value of $\frac{s\,(j-m)}{j\,(s-m)} \times 100$	Available Extraction.
43·2	92·7	95·5	45·0
62·3	91·9	94·7	64·4
77·4	91·1	94·0	79·5
85·4	90·8	93·7	87·4
90·1	90·4	93·2	91·8
93·1	90·1	92·9	94·4
95·7	89·8	92·6	96·9
97·4	89·5	92·3	98·4
100·0	88·9	91·7	100·0

Assuming that with lower initial purities the decrease in purity is proportional to that already found, in the four tables below are calculated the same data as in the two preceding tables for initial purities of 80 and 85.

Fraction.	Sucrose obtained per 100 Sucrose in cane.	Purity	Value of $\frac{s\,(j-m)}{j\,(s-m)} \times 100.$	Product of Cols. 2 and 4 ÷ 100.
1	43·2	85·0	87·4	37·9
2	19·1	82·2	84·0	16·1
3	15·1	80·4	81·7	12·3
4	8·0	80·7	82·0	6·6
5	4·7	76·3	76·2	3·6
6	3·0	74·1	72·9	2·5
7	2·6	72·4	70·3	1·9
8	1·7	69·6	65·6	1·2
Megass	2·6	59·6	45·5	1·2

Extraction.	Purity.	Value of $\frac{s\,(j-m)}{j\,(s-m)} \times 100.$	Available Extraction.
43·2	85·0	87·4	45·7
62·3	84·1	86·3	65·1
77·4	83·4	85·5	79·9
85·4	83·1	85·1	87·8
90·1	82·8	84·8	92·2
93·1	82·5	84·4	94·9
95·7	82·2	84·0	97·5
97·4	82·0	83·8	98·7
100·0	81·4	83·0	100·0

Fraction.	Sucrose obtained per 100 Sucrose in cane.	Purity.	Value of $\dfrac{s\,(j-m)}{j\,(s-m)} \times 100$	Product of Cols. 2 and 4 ÷ 100.
1	43·1	80·0	81·2	35·2
2	19·1	77·4	77·7	14·8
3	15·1	75·7	75·3	11·5
4	8·0	75·9	75·6	6·0
5	4·7	71·8	69·3	3·3
6	3·0	69·7	65·7	2·0
7	2·6	68·2	63·2	1·7
8	1·7	65·5	58·1	1·0
Megass	2·6	56·1	36·7	1·0

Extraction.	Purity.	Value of $\dfrac{s\,(j-m)}{j\,(s-m)} \times 100.$	Available Extraction.
43·2	80·0	81·2	46·0
62·3	79·2	80·1	65·4
77·4	78·5	79·2	80·4
85·4	78·3	78·9	88·2
90·1	77·9	78·4	92·6
93·1	77·7	78·1	95·1
95·7	77·4	77·6	97·4
97·4	77·2	77·3	98·7
100·0	76·6	76·5	100·0

The results so obtained lend themselves to graphic representation. In *Fig. 130* is plotted on the horizontal line the total extraction at each point, and on the vertical line the purities and amount of available sugar in the whole quantity of juice extracted. The product of the height of the available sugar curve at any point into the extraction at that point represents the available extraction at that point.

In no case is there reason to suppose that increasing the extraction will decrease the amount of available sugar due to a lower purity.

As regards the second conception stated above, local conditions are the dominant determining factor; the writer's attempt to solve the question was made for conditions as they were in certain factories in Mauritius, *circa* 1902, and is reproduced below from 'Sugar and the Sugar Cane.' *It cannot be too strongly insisted on that those interested should make the calculations themselves, using their own choice of data.*

Fig. 130.

Purity, or % Available Sugar.

Extraction.

Graph shewing fall in Purity and in Available Sugar with increasing Extraction.
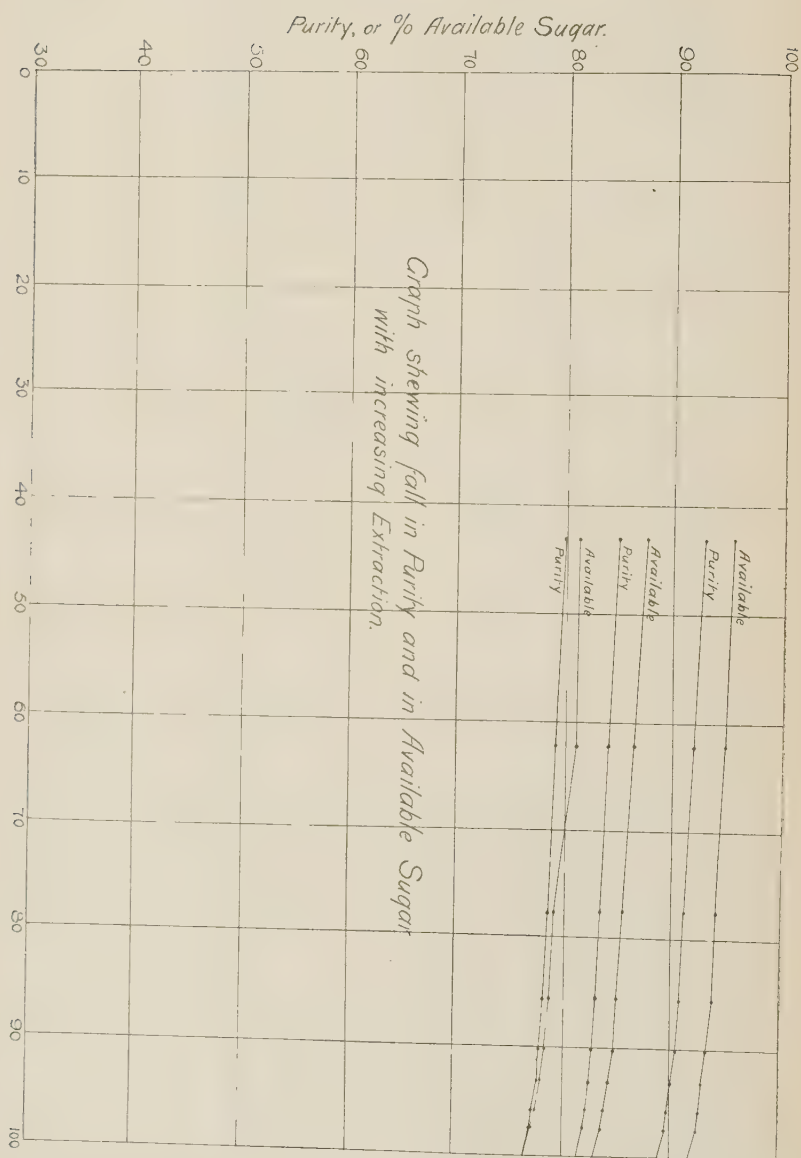
The chief factors in determining the economic limit are[7] :—

1. The type of crushing plant, whether two or three mills.

2. The degree of admixture of the added water.

3. The proportion of sugar extracted for market on the total brought into the juice as the result of maceration.

4. The thermal efficiency of the factory as a whole, including the boiler plant, the method of evaporation, triple or quadruple effect, and the general internal economy.

5. The money value of the marketed sugar.

6. The cost of coal or other fuel.

7. The fuel value of the extra sugar extracted.

8. The expenses of making, handling, transporting, &c., the extra sugar made.

9. The sugar content of the cane.

10. The cost of the increased evaporating and other plant to deal with the larger quantities of juice.

An attempt follows to unite all these factors into one expression.

Following on what has already been written, it is simply a matter of calculation to find what amount of extra sugar is extracted as the result of added water ; for this purpose the following data have been adopted :—

Canes (a).— 13·69 per cent. sugar, 12·00 per cent. fibre, crushed in the first mill to 30 per cent. fibre give 60 per cent. of juice, containing 16·15 per cent. sugar ; crushed further in a second mill to 45 per cent. fibre give 13·33 per cent. of juice, containing 15·34 per cent. sugar. The residual megass 26·67 per cent. on the canes contains 14·67 juice per cent. on cane, the juice containing 13·40 per cent. sugar.

Canes (b).—10·26 per cent. sugar, 12·00 per cent. fibre crushed as in the above case, give first mill juice 12·07 per cent. sugar, second mill juice 11·46 per cent. sugar, residual juice in megass 10·20 per cent. sugar.

To the megass from canes of the above composition let water be added after the second crushing, and let the megass be again crushed to the same fibre content. The amount of diluted juice obtained is evidently the same as the water added, and the amount of sugar brought into the juice can be easily calculated when the coefficient of admixture is known. In calculating the tables below a coefficient of ·85 has been adopted, and of the sugar thus brought into the juice ·85 is estimated as capable of extraction as marketable sugar. The value of this sugar is taken as £9 per ton or 1·90 cents per pound. The expenses of obtaining this sugar are ascertained on the following basis : The composition of the expressed diluted juice is calculated allowing a purity of 80 ; the tons of water necessary to be evaporated to concentrate this to 50° Brix, and then to masse cuite at 95° Brix, are calculated. Coal is taken as worth £2 at the furnace mouth, and to give for use in the factory per lb. burnt 8 lbs. steam, each 1 lb. capable of evaporating 3 lbs. in the triple and
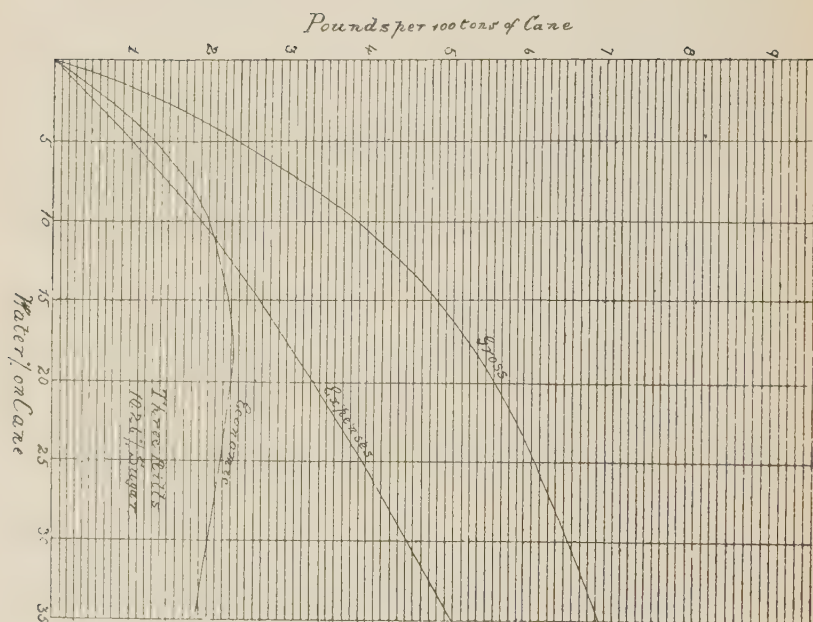
Fig. 131.
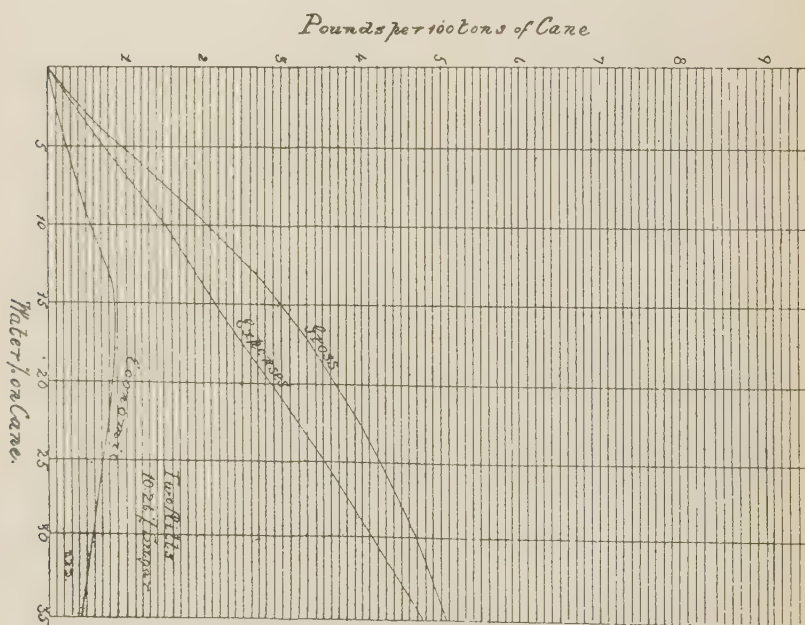
1 lb. in the pans; for heating the extra juice each ton is regarded as requiring ·016 ton coal. The expenses of evaporation are thus obtained. On reference to the tables below it will be seen that these expenses are practically constant for the different types of cane and crushing when the added water is the same, and that one ton of coal will, with the data adopted, account for twenty tons added water. If w tons water be added, the expenses are then ·w£ per 100 tons canes for heating and evaporation of extra juice.

The total amount of sugar washed out of the megass as the result of the maceration is calculated before the amount of marketed sugar is obtained; the sugar is valued as fuel at £1 per ton, with coal at £2 per ton, and to the values so obtained 10 per cent. is added to express the fuel value of other organic combustible removed. With the data adopted the value of the sugar, &c., as fuel is ·144 of the sugar markets. The other expenses, packages, handling, transport to port, &c., are estimated at 10s. per ton or ·055 of the value of the sugar marketed; the sum total of these last two sources of expenditure is then almost exactly ·2 of the value of the sugar marketed. The general expression then to give the value of maceration with the data adopted is: Net profit = £7·2S—·w£ per 100 tons of cane, S being the tons of sugar marketed, and w the tons of water added.

When only two mills are used, very different results are obtained; the method of calculation employed is then somewhat different. After the canes have been crushed to 30 per cent. of fibre, water is supposed to be added, and the megass crushed to 45 per cent. of fibre; the sugar obtained is calculated on the supposition of complete admixture; the excess over that obtained by simple dry crushing to the same fibre content has already been given, and 85 per cent. of this excess is taken as the extra sugar brought into the juice as the result of maceration. The other calculations are made as detailed above.

The results of these calculations just indicated are given in the appended tables, and are also expressed as curves in *Figs. 131* and *132*. The curve marked 'gross' represents the value of the extra product obtained at £9 per ton, and the curve marked 'expenses' gives the expenditure, and that marked 'economic' the profits.

Three points bearing on the subject have not been included in the above calculations. Firstly, no allowance has been made for decreased purity of the juice; in the writer's experience this is not serious. Secondly, no allowance has been made for increased consumption of steam to drive the third mill. With a modern engine, and where the exhaust is used in evaporation, this is a small item. And, thirdly, there is the question of increased initial cost for enlarged boilers and evaporating plant. Referring to the 'economic' curves it will be seen that as the curves approach the maximum, the increase in the profits is very slow. In designing a new plant, this might well indicate the financial economy of arranging for a dilution of from 5 per cent. to 10 per cent. less than the indicated maximum.
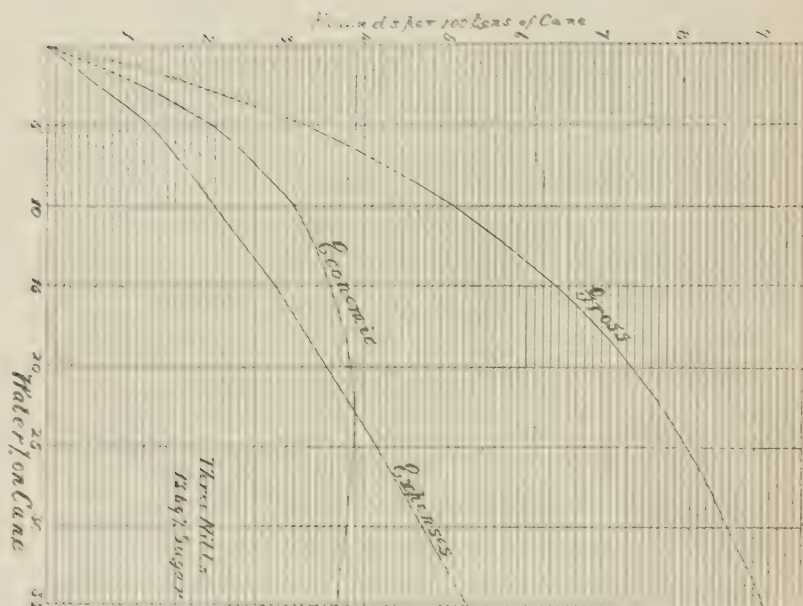
Fig. 132.
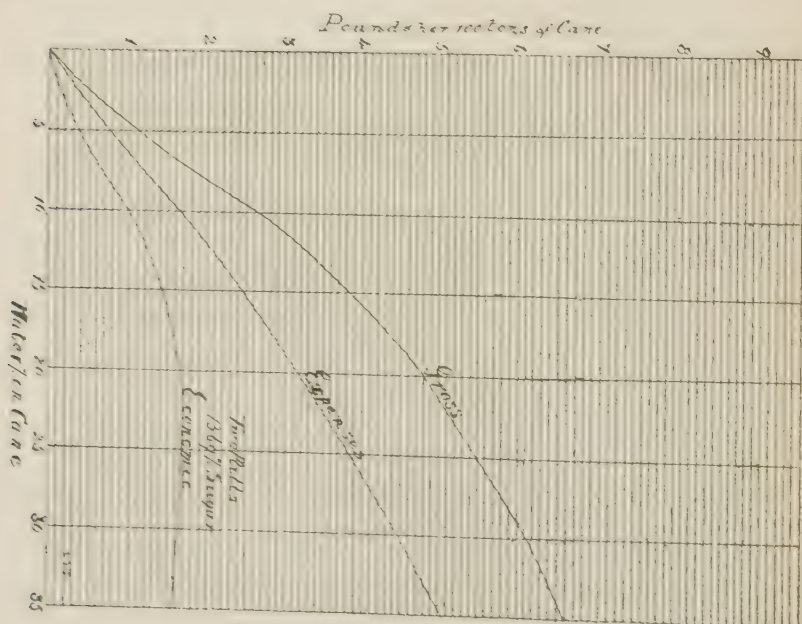
THE EXTRACTION OF JUICE BY MILLS.

On examining the tables and curves it is at once apparent that the main factor in determining the economy is the relative value of sugar and coal; any variation from the ratio adopted here entirely alters the conditions, and an unfavourable alteration might easily, in the case of a poor cane and two mills, convert the estimated profits into a loss. The second point to be noticed is that whatever the admixture, the expenses of evaporation remain the same; a lower coefficient than that adopted here would also in many cases, indicate a loss. Thirdly, the great financial profit due to a third mill is clearly shown.

CANES 13·69 PER CENT. SUGAR. THREE MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and evaporation	·53	1·05	1·57	2·06	2·57	3·08	3·56
Handling, packages, transport, &c.	·18	·29	·36	·41	·44	·47	·50
Sugar, &c., as fuel..	·47	·74	·93	1·06	1·16	1·23	1·29
Total expenses	1·18	2·08	2·86	3·53	4·17	4·78	5·35
Marketed sugar	3·24	5·18	6·45	7·37	8·05	8·56	9·01
Profits	2·06	3·10	3·59	3·84	3·88	3·78	3·66

CANES 13·69 PER CENT. SUGAR. TWO MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and evaporation	·51	1·04	1·55	2·06	2·55	3·07	3·54
Handling, packages, transport, &c.	·06	·14	·20	·25	·29	·32	·35
Sugar, &c., as fuel	·20	·47	·69	·84	·98	1·04	1·16
Total expenses..	·77	1·65	2·44	3·15	3·82	4·43	5·05
Marketed sugar	1·14	2·66	3·86	4·80	5·49	6·11	6·57
Profits	·37	1·01	1·42	1·65	1·67	1·63	1·52

CANES 10·26 PER CENT. SUGAR. THREE MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	·25	30	35
Heating and evaporation	·53	1·03	1·56	2·06	2·56	3·07	3·56
Handling, packages, transport, &c.	·13	·22	·27	·31	·34	·36	·38
Sugar, &c., as fuel	·35	·66	·83	·95	1·04	1·10	1·16
Total expenses	1·01	1·91	2·66	3·32	3·94	4·53	5·10
Marketed sugar	2·36	3·93	4·89	5·61	6·03	6·54	6·93
Profits	1·25	2·02	2·23	2·29	2·09	2·01	1·83

CANES 10·26 PER CENT. SUGAR.   TWO MILLS.

Cost or Value of in £ Sterling.	Tons added Water per 100 tons of Cane.						
	5	10	15	20	25	30	35
Heating and evaporation	·49	·99	1·46	2·03	2·55	3·04	3·53
Handling, packages, transport, &c.	·05	·11	·16	·19	·22	·24	·27
Sugar, &c., as fuel	·17	·42	·54	·67	·76	·85	·92
Total expenses	·71	1·52	2·16	2·89	3·53	4·13	4·72
Marketed sugar	·97	2·07	3·06	3·69	4·25	4·70	5·13
Profits	·26	·55	·90	·80	·72	·57	·41

The Structure of the Cane as affecting Milling.—The

very brief account of the cane given in *Chapter I.* will have shown that it is of a very complicated structure; the three principal structures are the rind, the pith, and the fibro-vascular bundles. From the milling point of view the cane may be regarded as composed of rind, pith, and nodes, the last being intermediate in composition between the two first. The writer made a number of analyses of canes, dividing them into rind, pith, and nodes. The results are as shown in the following table : —

	Rose Bamboo.	Y. Caledonia.	Lahaina.	Lahaina.	Y. Caledonia.
	Oahu.	Oahu.	Oahu.	Maui.	Kauai.
Whole Cane.					
Weight per cent. cane.	100·00	100·00	100·00	100·00	100·00
Juice per cent.	87·12	84·91	86·25	88·40	84·45
Fibre per cent.	12·88	15·09	13·75	11·60	15·55
Solids per cent.	14·70	15·83	16·03	20·10	17·92
Sugar per cent.	13·25	13·04	13·28	18·14	15·36
Water per cent.	72·12	69·08	70·22	68·30	66·53
Pith.					
Weight per cent. cane.	74·28	66·90	72·45	61·77	67·15
Juice per cent.	91·90	90·43	90·11	94·78	91·20
Fibre per cent.	8·10	9·87	9·89	5·22	8·80
Solids per cent.	15·93	17·34	17·45	22·21	19·62
Sugar per cent.	14·80	15·06	15·11	21·11	17·52
Water per cent.	75·97	73·09	72·66	72·57	71·60
Rind.					
Weight per cent. cane.	9·57	15·27	12·28	14·34	15·80
Juice per cent.	62·11	65·92	72·73	69·98	64·92
Fibre per cent.	37·89	34·71	27·27	30·02	35·08
Solids per cent.	9·38	11·52	11·54	15·40	13·87
Sugar per cent.	6·46	7·44	7·50	11·10	10·00
Water per cent.	52·73	53·77	51·19	57·58	51·05
Node.					
Weight per cent. cane.	16·15	17·83	15·27	23·89	17·05
Juice per cent.	79·98	80·40	78·78	82·80	75·97
Fibre per cent.	20·02	19·60	21·22	17·20	24·03
Solids per cent.	12·22	13·86	12·88	17·43	15·07
Sugar per cent.	10·14	10·27	9·22	14·62	11·83
Water per cent.	67·76	66·54	65·90	65·37	60·90

	Rose Bamboo.	Y. Cale-donia.	Lahaina.	Lahaina.	Y. Cale-donia.
	Oahu.	Oahu.	Oahu.	Maui.	Kauai.
Absolute Juice.					
Weight per cent. cane.	87·12	84·91	86·25	88·40	84·45
Solids per cent.	16·87	18·52	18·59	22·72	21·22
Sugar per cent.	15·22	15·35	15·39	20·52	18·19
Purity	90·22	82·94	82·79	90·32	85·71
Pith Juice.					
Weight per cent. cane.	68·26	60·49	65·49	58·62	61·24
Solids per cent.	17·33	19·17	19·37	23·43	21·49
Sugar per cent.	16·10	16·65	16·76	22·27	19·20
Purity	92·90	86·85	86·53	95·05	89·29
Rind Juice.					
Weight per cent. cane.	6·04	10·06	8·91	10·00	10·26
Solids per cent.	15·08	17·41	15·87	22·00	21·37
Sugar per cent.	10·40	11·29	10·30	15·86	15·40
Purity	69·10	64·85	64·91	72·09	72·10
Node Juice.					
Weight per cent. cane.	12·82	14·36	11·85	19·78	12·95
Solids per cent.	15·28	17·24	16·29	21·05	19·83
Sugar per cent.	12·68	12·77	11·70	17·66	15·57
Purity	82·98	74·07	71·81	83·90	78·50

Canes very similar to those used in the above described experiments were then crushed in a hand mill; the megass was divided into two parts, one representative of the pith and one of the rind; these were weighed and analysed separately with the results shown below :—

	Lahaina.	Rose Bamboo.	Y. Caledonia.	Y. Caledonia.
	Maui.	Oahu.	Kauai.	Oahu.
Expressed Juice.				
Weight per 100 cane	70·99	66·75	65·60	64·64
Solids per cent.	24·22	17·70	21·68	18·73
Sugar per cent.	21·94	16·42	18·42	16·85
Purity..	90·58	92·77	84·97	89·96
Pith Megass.				
Weight per 100 cane	13·35	15·74	14·40	14·69
Solids per cent.	15·29	11·57	12·20	12·20
Sugar per cent.	13·46	10·32	9·00	10·00
Water per cent.	52·32	56·16	49·21	54·52
Fibre per cent.	31·39	31·27	38·59	33·28
Rind Megass.				
Weight per 100 cane....	15·66	17·51	20·00	20·67
Solids per cent.	13·26	9·40	11·09	9·92
Sugar per cent.	10·37	7·22	7·45	5·68
Water per cent.	53·90	54·00	46·68	49·97
Fibre per cent.	32·84	36·60	42·23	40·11

This experiment shows that with a '*crushing*' up to 70 per cent. very little 'rind juice' is extracted.

Megass collected from factories was also divided into two parts representative of the pith and rind; each part was analysed separately with the following results:—

	Mill 1.	Mill 2.	Mill 3.	Mill 4.
Pith Megass.				
Weight per 100 megass..	53·33	48·62	50·0	51·25
Sugar per cent.	11·33	7·19	3·78	2·87
Fibre per cent.	33·59	41·58	45·63	46·91
Rind Megass.				
Weight per 100 megass	46·67	51·38	50·0	48·75
Sugar per cent.	9·12	7·13	4·34	4·06
Fibre per cent.	35·15	41·54	44·90	46·67
Whole Megass.				
Weight per 100 megass..	100·0	100·0	100·0	100·0
Sugar per cent.	10·34	7·16	4·06	3·51
Fibre per cent.	34·32	41·56	45·26	46·87

These analyses bring out the fact that the pith megass, originally the sweetest, is much more extracted than the rind megass, from which the process of milling has taken comparatively little sugar.

These results are approximately summarized in the following table which conceives the cane as composed of pith and rind, from the former of which a high extraction is obtained, a very efficient one resulting from the hard impervious rind :—

				Mill 1.	Mill 2.	Mill 3.	Mill 4.
	Extraction per 100 sugar in pith..			91·6	95·7	97·9	98·5
	,,	,,	cane ..	78·5	82·0	83·9	84·5
	,,	,,	rind .	22·2	48·3	71·0	73·9
	,,	,,	cane..	3·2	6·9	10·1	10·5
Total	,,	,,	,, ..	81·7	88·9	94·0	95·0

REFERENCES IN CHAPTER XI.

1. *La. Planter*, xli., 299.
2. *La. Planter*, xxxvii., 261.
3. *Arch.*, 1896, p. 222.
4. *Proc. Inst. Mech. Eng.*, Nov., 1902.
5. After *Bull. 22. Agric. H. S. P. A.*
6. After *Bull. 30. Agric. H. S. P. A.*
7. *I. S. J.*, 68.

CHAPTER XII.

THE DIFFUSION PROCESS.

In the process described in the previous chapter the juice is extracted from the cane by rupture of the cells which contain the juice. In the diffusion process an entirely different system of extraction is carried out, the principle of which is as under:—If a solution of a soluble body such as sugar contained in a cell, the walls of which consist of some porous material, for example, unglazed earthenware, parchment, or the woody cells of which plants are built up, be immersed in a vessel of water, it is found that the sugar solution passes out through the porous wall into the water and that water enters the cell; this process continues until the solution on both sides of the cell is the same. It is not all bodies that possess this property. Those which do not, for example, gummy bodies, are termed colloids, and in general it is found that it is crystalline bodies that possess the property of passing through a porous membrane; to this phenomenon the name of osmosis or diffusion is given.

The sugar cane consists of a vast number of cells, in the interior of which the juice is contained; and the diffusion process applied to the extraction of juice consists of systematically allowing the juice in these cells to diffuse into water or diluted juice. In the diffusion process the cane is cut into fine slices about one-twentieth of an inch thick. These slices, technically called chips, are placed in vessels known as cells or diffusers, and are systematically washed until a very high degree of exhaustion is obtained. The system of working is roughly this: Suppose that there are twelve cells in use, these are all connected so that juice from one cell can be passed on to the next succeeding one; into a cell fresh chips are introduced; water that has passed over eleven sets of chips is forced into this cell, and after diffusion has taken place a charge of juice is withdrawn, and water which has passed over ten sets of chips takes its place. This process continues until water alone enters the cell. The highly diluted juice passes on in the above-described routine, and the chips are discharged to be, in general, crushed in a mill to remove water before use as fuel.

The essential parts of a diffusion plant are described below.

Cane Cutter.—A type of cane cutter that has been largely used is shown in vertical section in *Fig. 133;* on a vertical spindle *b*, belt-driven from the pulley *d*, by means of the bevel wheels *c*, is carried a disc *e*. The whole

is enclosed in a sheet iron casing h and closed by a strong cover g; fastened on to the disc e are a number of boxes varying from six to twelve, each of which carries a strong sharp knife. The knives are fixed on the disc exactly similar to the cutting edge of a carpenter's plane, and the knife boxes are arranged so
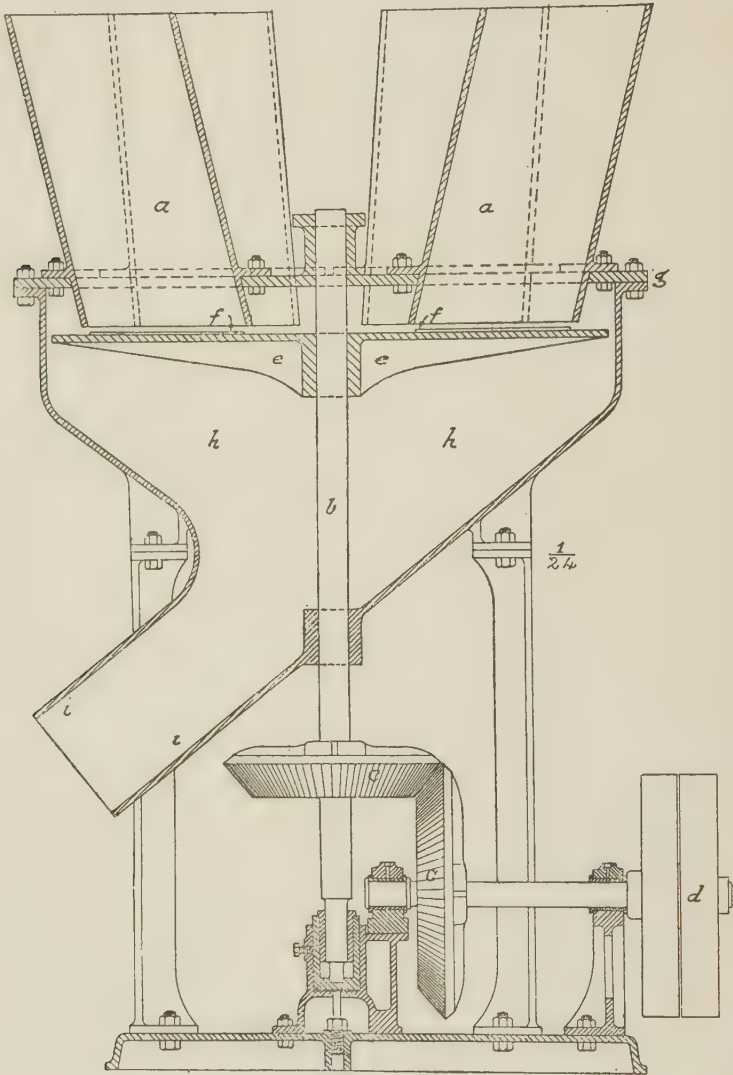
Fig. 133.

that they may readily be removed from the disc and spare knives substituted when one set has become blunted. A plan of the disc with an arrangement of twelve knives is shown in *Fig. 134.* Securely fixed to the cover are one, two or more hoppers a into which are fed the canes, which descend on to the disc by their own weight. A high speed is given to the disc, from 100 to 150

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revolutions per minute, and the knives cut the cane into chips one-twentieth of an inch or more in thickness, dependent on the setting of the knives. The hoppers are made either vertical or at an angle—the former giving round and the latter oval chips. The chips fall into the receptacle formed by the sides of the apparatus below the disc, and thence pass on to the shoot. The cutter is variably placed above or below the diffusion battery. Cane cutters of this type differ in details. They are sometimes directly driven without the inter-position of belt gearing, and are also sometimes over instead of under-driven, as shown in *Fig. 133*. The shoot *i* is also sometimes dispensed with and its place taken by a scraper actuated by the shaft *b*. In this case the bottom of the receptacle *h* is flat, or nearly so, and the chips are swept out through an opening in the bottom.
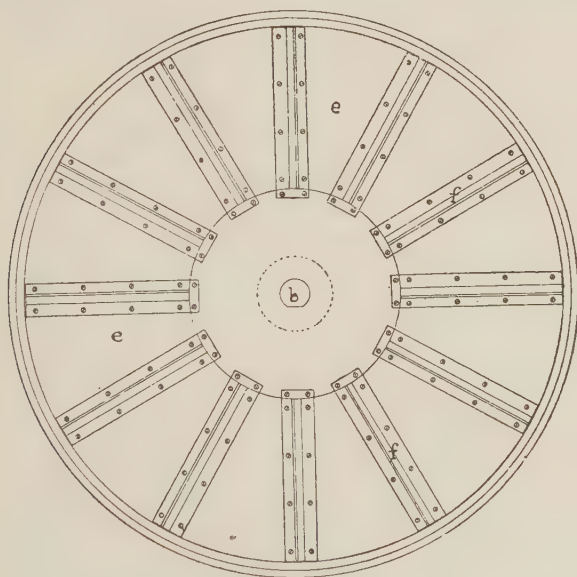
Fig. 134.

To work up 300 tons of cane in twenty-four hours, a plant of this nature will be about 5 ft. in diameter. The capacity depends on the number of hoppers, and on the setting of the knives, whether to give thick or thin chips. More cane can be cut when thick chips are allowed, but the efficiency of the after process of diffusion is diminished.

Diffusion Cell.—A section through a cell of a diffusion battery, along with its accompanying juice heater, is shown in *Fig. 135*. It consists of a cylindrical vertical shell, the bottom being made with a slight slope, and the top fitted with a head box; the cell is closed by a door on the top, which is clamped tight by the screw and lever shown at *b*; by slackening the screw the door can be slung on one side, to allow of a charge of chips being intro-duced. Round the bottom part of the cell is fixed a perforated false bottom *d*,

the object of which is to prevent pieces of cane being carried along the pipe *c*. In some designs the lower door itself carries the false bottom. The joint in the lower door is a hydraulic one, consisting of a hollow rubber tube provided with a pipe by means of which water is conducted to the tube, which is placed
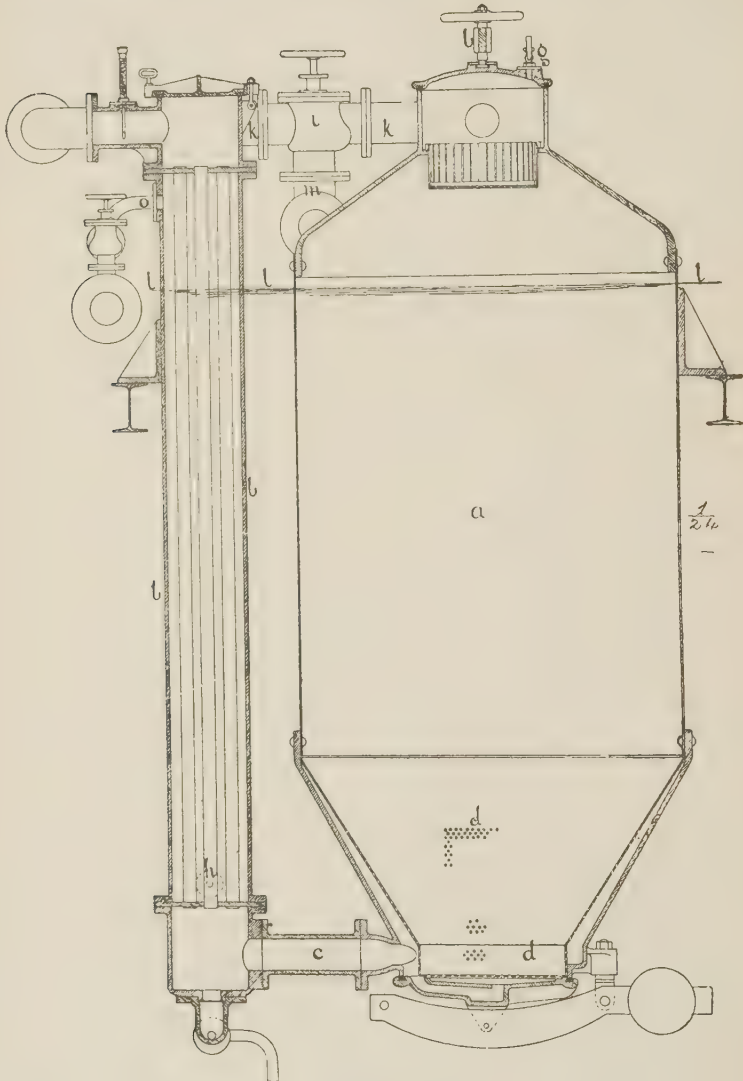
FIG. 135.

in a circular groove contrived either in the door itself or in the bottom of the cell. The water which fills this tube is taken from a tank at a high level, so that in all cases the pressure in the tube is greater than the pressure in the cell. In other cases the rubber tube is connected by a pipe with the main

steam; the direct steam becomes condensed in the coil, and pressure is made in the rubber tube by the steam acting on the condensed water.

Attached to each cell or dipper is the juice heater b; this is of the vertical tube type, exhaust steam being admitted at o, and the condensed water drawn off at p. Communication between diffuser and juice heater may be made either at top or bottom by the pipes k or c. The main juice circulating pipe is shown at m, the controlling valves or cocks appearing at i. The floor level on which the operator stands is at the line l, all valves and cocks being within easy reach; g is a small pipe let into the cover of the diffuser to act as an air vent to allow the air to escape when the diffuser is being filled.

Elevators.—The other adjuncts of the diffusion battery which remain to be described are the elevator and charging apparatus; these are very varied in design and arrangement. In case the canes are sliced on the basement, they are elevated to a floor above the level of the battery by means of an endless scraper carrier similar to those employed to convey megass to the boilers; in other cases, the cane cutting machine is placed above the level of the diffusion battery, and the canes are elevated as such, and the sliced cane distributed directly from the cutting machines.

Charging.—The method by means of which the cells are filled with chips varies with the arrangement of the battery; the latter may be arranged either as a circular or as a line battery. In the former case the cutter is placed about twenty feet above the level of the top of the cells and directly over the centre of the battery, or in case the canes are cut on the basement the chips are elevated to a hopper similarly placed. The hopper or cane cutter is mounted on rollers, so that it can be revolved through a complete circle. The hopper terminates in a shoot, the discharge of which can thus be brought over any cell at will. When the cells are placed in line, the chips cut on the basement are delivered into a truck running on an over-head line, from which pass shoots directing the chips to the diffusers. Line batteries are generally placed in two parallel rows, between which is the platform on which the attendants stand.

Circulation.—The water requisite for the diffusion process is contained in an overhead tank, placed considerably above the level of the diffusers. The circulation of juice throughout the battery is secured by means of the hydrostatic pressure obtained from the head of water in this tank. When it is desired to empty a cell of its liquid contents, this hydrostatic pressure cannot of course be used, and an air compressor, in nearly all cases, forms a part of the plant. The latter is used also in starting the first round of the battery, and afterwards in the regular routine when a cell contains exhausted chips.

Working of the Battery.—In *Fig. 136* is given a plan of a twelve-cell line battery, arranged in two rows, showing the pipe connections between cells and heaters, and in *Fig. 137* a diagrammatic sketch of a battery intended to illustrate the method of working. Let the battery consist of twelve

elements which may be arranged as a line or circular battery. The pipe line W represents the water main connected to the overhead tank, and that marked J the juice main. Let it be cell No. 1 that is the first to be filled with chips; the three or four last cells of the battery are first filled with water. To do this the cock W 9 is opened, and water flows into cell No. 9. When No. 9 is three-parts full the top door is closed, and as soon as water escapes through the air vent the valve W 9 is closed. No. 10 is now filled, but in a different way; the valves J 9 and J 10, are opened and also W 9. Water then flows from cell No. 9 up juice heater No. 9, through the valves in the juice main J 9 and J 10, down juice heater No. 10 and up into diffuser No. 10. It will be seen that water passes through two juice heaters and enters the cell from the bottom; in this way the air is free to escape. This method of filling a cell is termed in French *meichage*. Cells Nos. 11 and 12 are then filled in a precisely similar manner. During the passage of the water through the juice heater it is heated and enters the cells at a temperature of about 200° F.

By this time cell No. 1 will have been filled with chips, and is now ready to receive hot water from cell No. 12. The water is passed into cell No. 1 in the manner described as *meichage*, as soon as juice passes out through the air vent. The direction of the flow of water is reversed by closing the valve J 12 and opening the circulation valve C 12, so that the flow is now from top to bottom.

In the meantime, cell No. 2 has been filled with chips, and the operations described in connection with cell No. 1 are carried out in a precisely similar manner. When five or six cells have been filled with chips in this way, those that were at first filled with water are emptied. To do this, the hydrostatic pressure is replaced by air pressure from the air compressor, the water connections being shut off. When cell No. 6 has been filled with chips and water, the first charge of juice is drawn. To do this the direction of the flow is changed in this cell from top to bottom, the circulation valve is opened and the juice valve shut; at the same time the valve connecting the juice main to the measuring tank is opened. The juice from cell No. 6 will flow along the juice main under either the influence of hydrostatic pressure from the overhead tank or air pressure from the air compressor. When the proper amount of juice has been drawn, the valve leading from the juice main to the measuring tank is closed, and cell No. 7 is filled by *meichage*. The chips in cell No. 1 are now exhausted, the door at the bottom is opened and the chips are discharged on to a carrier, which conveys them to a mill where they are crushed and passed on to the boiler wall for fuel.

After the first charge has been drawn from cell No. 6, a charge is drawn from cell No. 7, and so on from each cell of fresh chips until that cell is reached which was the first to be filled with chips. The first round of the battery is now complete, and the regular routine recommences. Two cells are always out of circuit, one filling and one being prepared for fresh chips.

Each time a cell is filled with fresh chips a charge of juice is drawn and a cell of exhausted chips emptied.

The following notes on the quantity of juice to draw are taken from Spencer[1] : —
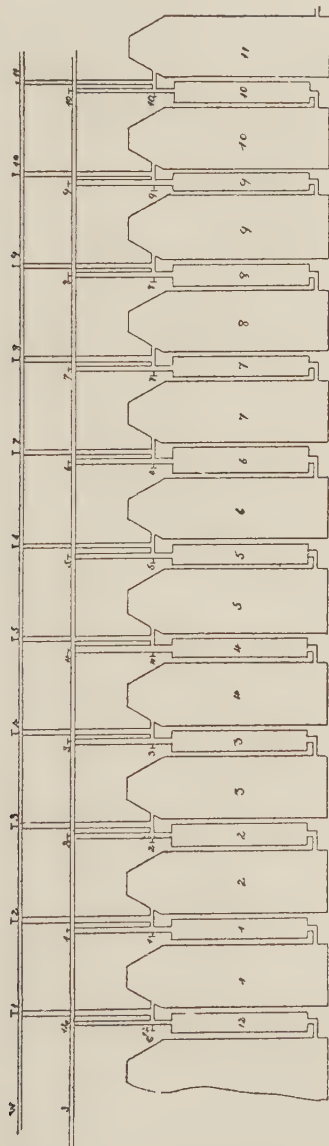
FIG. 136.

" With a constant percentage of sucrose in the normal juice, a uniform draw and a perfectly regular extraction, the dilution and consequently the per cent. sucrose in the diffusion juice will vary considerably. This variation is due to the variable juice content of the cane. In ordinary seasons in

Louisiana the per cent. juice in plant cane will average about 91, and in stubble (ratoons) about 89, consequently if we draw the same amount of juice when diffusing cane as we do with stubble, the dilution will be lower, and the analyses of the two juices will vary, even though the normal juices contain the same per cents. of sucrose. It is safe to commence working with a dilution of about 23 per cent., estimating on a average about 90 per cent. of juice in the cane. If the extraction is satisfactory, but the density of the diffusion juice too low, the cane contains less than 90 per cent. of juice, and the draw should be reduced until a satisfactory density is obtained. With thin chips and regular work the draw may be reduced to 18 per cent., but it is not safe to go beyond this limit, except when there is a careful chemical control to promptly detect and remedy a poor extraction. With the best multiple effect evaporation it is economical to burn more coal to evaporate additional water rather than leave two to three-tenths per cent. sugar in the chips, which might have been obtained by a little higher dilution."

The following table, designed for preliminary work, gives the dilution for different quantities of juice drawn :—

Table showing the apparent dilution of the normal juice corresponding to different quantities of juice drawn.

(This table is based on assumed juice content in the cane of 90 per cent. and of an average density of 16° Brix.)

Apparent Dilution. Per cent.	Diffusion Juice Drawn per 100 lbs. Cane.			Apparent Dilution. Per cent.	Diffusion Juice Drawn per 100 lbs. Cane.		
	Weight Lbs.	Gallons.	Litres.		Weight Lbs.	Gallons.	Litres.
10	99·0	11·2	42·3	21	108·9	12·4	46·9
11	99·9	11·3	42·7	22	109·8	12·5	47·2
12	100·8	11·4	43·1	23	110·7	12·6	47·6
13	101·7	11·5	43·5	24	111·6	12·7	48·0
14	102·6	11·6	43·8	25	112·5	12·8	48·4
15	103·5	11·7	44·2	26	113·4	12·9	48·8
16	104·4	11·8	44·6	27	114·3	13·0	49·1
17	105·3	11·9	45·0	28	115·2	13·1	49·5
18	106·2	12·0	45·3	29	116·1	13·2	44·9
19	107·1	12·2	46·1	30	117·0	13·4	50·6
20	108·0	12·3	46·5				

Temperature.—A very important point in connection with diffusion work is the temperature to which the juice should be heated. The following temperatures are given by Llewellyn Jones[2] as prevailing in the diffusion battery at Non Pareil in Demerara :—No. 1, 75° C.— 80° C. ; No. 2, 80° C. —85° C. ; No. 3, 85° C.—90° C. ; No. 4, 95° C.—100° C. ; Nos. 5-9, 100° C. ; No. 10, 90° C. ; No. 11, 85° C.
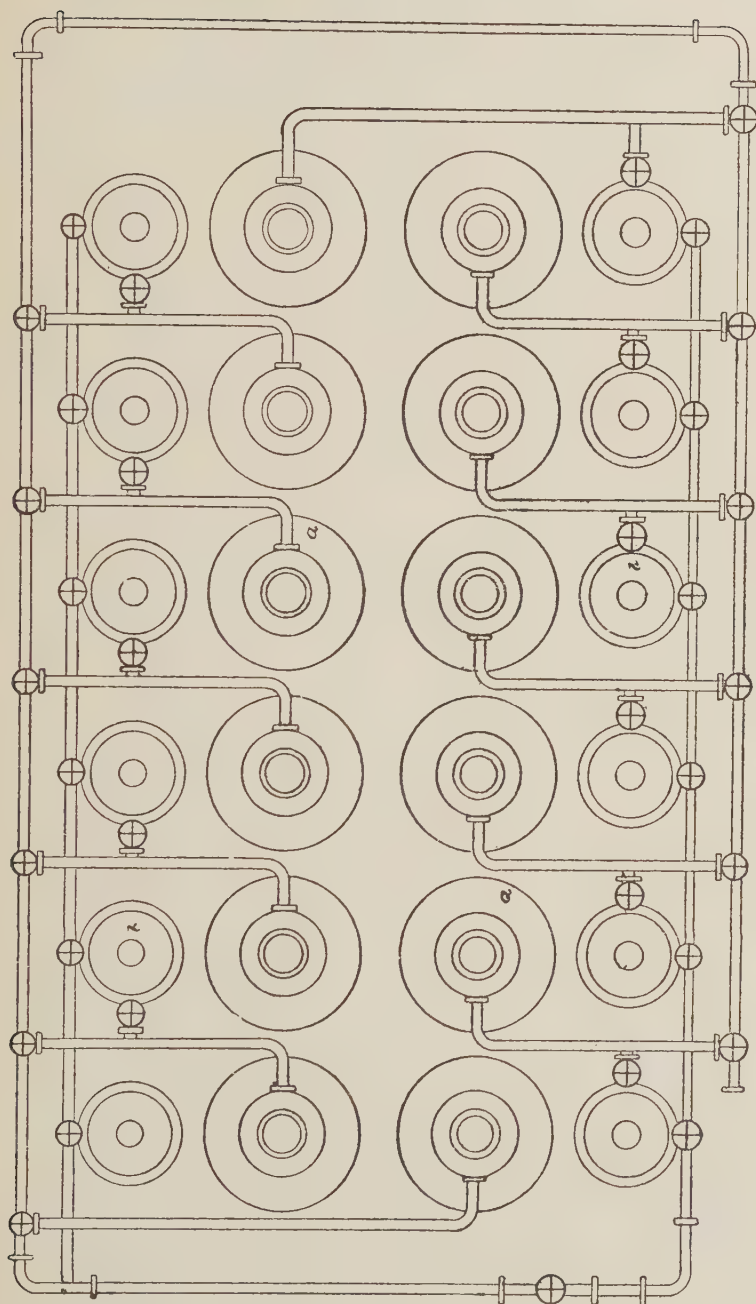
Fig. 137.

At the United States Government experiment station at Magnolia during the season 1888–89 the following were the temperatures maintained:—

Cell No.	1	2–7	8–10	11	12
Temp. F.°	140	158–176	203	185	160

The temperature and densities in the different cells at Wonopringo, Java, are shown in the following table:—

Cell.	Density.	Degree Brix.	Sugar Per cent.	Purity.	Temperature °C.
Normal juice	1·067	16·4	14·55	87·50	—
1	1·054	13·4	11·66	87·01	69
2	1·036	9·0	7·53	83·66	77
3	1·028	7·1	5·95	83·80	92
4	1·023	5·8	4·64	80·00	91
5	1·019	4·9	3·88	79·18	89
6	1·015	3·9	3·09	79·23	88
7	1·013	3·4	2·67	78·52	87·5
8	1·010	2·6	1·98	76·15	88
9	1·007	1·9	1·42	74·73	87
10	1·005	1·4	1·02	72·85	90
11	1·004	1·1	·85	77·27	92
12	1·0015	·4	·29	72·50	92
13	1·0003	·15	·06	40·00	91

It is in the cells last in series—*i.e.*, those containing the fresher chips—that the temperature should be highest; the higher the temperature the better the diffusion, and by maintaining a high temperature in the last cells, these are made to do as much work as possible.

Influence of Number of Cells.[3]—As the number of cells in a battery increases, so also does the extraction, the amount of water used remaining the same; simultaneously the dilution decreases. Thus with mill juice of 19° Brix in a 10-cell circuit the juice drawn off was of 13·1° Brix, but with a 16-cell circuit it was of 16·0° Brix. These figures were obtained in an experimental trial in Java in 1885. An insufficient number of cells seems to have been a weak point in the design of several of the Naudet outfits (*v. infra*).

Difference between Mill and Diffusion Juice.—Diffusion juice is invariably purer than the juice extracted by milling. In milling, the joints of the cane and the fibro-vascular bundles are ruptured and afford a juice much less pure than that given by the pith cells. In diffusion the gummy matters diffuse less quickly than the sugars, and owing to the high temperature a portion of the albuminoids is coagulated within the cell, and does not pass into subsequent processes. This point is illustrated by the following analyses from a Cuban factory working mills and diffusers simultaneously:—

	Krajewski Breaker.	First Mill.	Second Mill.	Diffusion.
Density..............	1·088	1·080	1·078	1·062
Sugar, Volume per cent.	20·43	18·62	17·80	14·83
Glucose ,, ...	·34	·33	·33	·28
Non-sugar ,, ...	2·01	2·25	2·54	1·32
Purity	89·7	87·8	86·5	90·3

Comparison between Milling and Diffusion.—The diffusion process as applied to the cane sugar industry first came into prominence about 1884, and since that date it has received extended trials; amongst the plants that have been erected may be cited those at Non Pareil in Demerara, at Britannia in Mauritius, at Makaweli and Kealia in the Hawaiian Islands, and at Wonopringo in Java; these factories, all of which were worked under expert supervision, have nevertheless reverted to milling, and the same is true of the majority of diffusion plants that have been erected. However, diffusion cannot be considered as dead, as several of the older plants remain in successful operation, and a few others have been erected in recent years. The causes that contributed to the non-success of the earlier diffusion plants were :—

1. Faulty design on the part of the engineering firms responsible for the machinery; this was especially pronounced in connection with the cane cutting machinery.

2. Difficulty in maintaining a constant supply of cane for day and night work. In a diffusion process, it is essential that the work be continuous; with milling this is not the case as the process of extraction is limited to the very small amount of material actually being crushed at any moment; it is this point, as much as any other, that tells against the diffusion process, as it is often impossible to maintain a continuous supply of cane; in the beet sugar industry the raw material is stored in silos without deterioration, thus affording a continuous supply, but such a process is not possible with the cane.

3. Greater elasticity of the milling process. The amount of cane treated in mills can be varied within wide limits without affecting the efficiency of the work, and with poor canes the economic limits of exhaustion can be controlled more readily than is the case in a diffusion process.

4. Excessive fuel consumption. In Demerara, a consumption of a ton of coal to a ton of sugar was common with the diffusion process; when it is recalled that at the present time there are beet factories working with a coal consumption of only seven per cent. on the weight of the beets, equal to half a ton of coal per ton of sugar, it is at once apparent that this enormous consumption was due, not to faults inherent in the diffusion process, but rather to the design of particular factories.

In 'Sugar and the Sugar Cane' (1904) the writer quoted 93·5 per cent. extraction as the highest figure recorded for mill work with a dilution of 21·65 per cent. on a normal juice. At the present moment (1909) in Hawaii there are quadruple crushing plants at work, obtaining an extraction averaging 95 per cent. without fuel consumption other than that afforded by the megass. The best work claimed for diffusion is an extraction of 96 per cent. to 98 per cent. but in no case is this obtained without a considerable consumption of extra fuel, and with a dilution higher than that found in milling processes.

Mixed Extraction Processes.—Below are given brief descriptions of combined milling and diffusion processes that have attracted attention.

Kessler Process.—The *Kessler*[4] mixed process of extraction works on somewhat different lines, and has for its object the extraction of sugar from megass by a continuous process, only one diffuser being used. The apparatus may be described as an upright U-shaped continuous tube, into which megass direct from the mill is fed. Falling into this tube the megass is carried forward by a screw conveyer, forced along in a compact mass, and discharged at the other end of the tube. At one end of the tube, opposite to that at which the megass enters, water under pressure is pumped in and travels along the
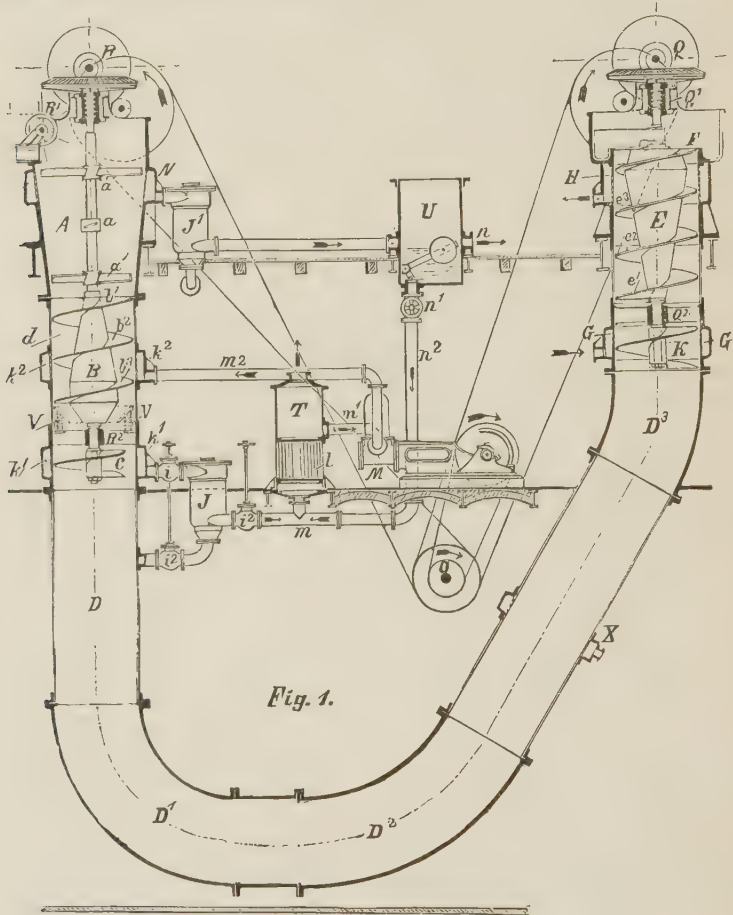
FIG. 138.

tube in a direction opposite to that along which the megass moves, and discharges at the end the megass enters. After the diffused megass has finally passed through the current of water, it is caught by a screw conveyer which subjects it to considerable pressure and discharges it from the apparatus. The megass after leaving the diffuser is crushed in a mill, and the highly diluted juice thus expressed is returned to the diffuser. This process is illustrated in *Fig. 138.*
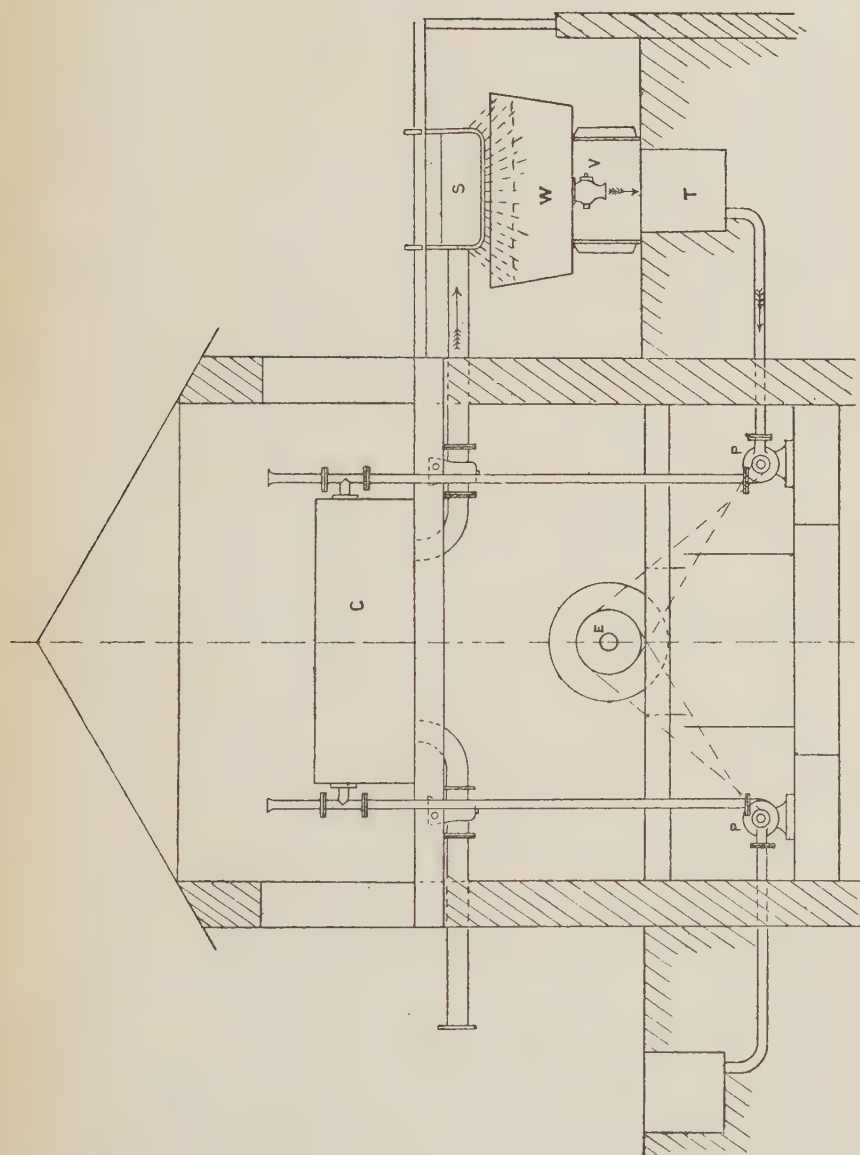
Fig. 139.

Perichon Process.[5] —This method was originated at the Rodah factory of the Daira Sanieh in Egypt. The dry crushed megass is received in trucks in which it is systematically diffused; the trucks are mounted on wheels and run on a tram line; at the bottom of the trucks is a strainer and discharge valve whereby the liquid contents of a truck can be drawn off, pumped to an overhead tank, and transferred to the next truck in series. The time allowed for diffusion in each operation is seven minutes. The weight of cane treated in 24 hours was 1000 tons, and the trucks used held about one and three-quarter tons of megass and were of 90 hectolitres capacity ($=316$ c.ft.); the megass was diffused in all nine times, the drawn off liquor being about 6° to 8° Brix in density, and of purity but little less than that of the expressed juice. After the final washing, the megass is crushed for fuel, the expressed water containing about five grms. sugar per 100 c.c., which would of course be the loss per 100 cane if the discharged megass weighed the same as the cane. In *Figs. 139 and 140* are given diagrammatic views of the installation.

The Naudet Process.—In the ordinary process of diffusion, that cell last filled with sliced cane is subjected to the operation known as '*meichage*' *i.e.*, the cell is filled from the bottom upwards with juice from the preceding cell, and on drawing off the direction of flow is reversed; in this process the juice at the bottom is more dilute and is actually the portion that is first drawn off; in addition, the upper layers of juice having passed over the slices of cane are colder than the lower layers. The Naudet patents refer to a system of forced circulation and re-heating, whereby the objections inherent to the usual process of '*meichage*' are overcome, and are expressed in the following words in the English patents.

" The application of forced circulation to every succeeding cell of a series of cells of a diffusion or macerating battery is accomplished by the use of a pump, the suction side of which communicates with the bottom of the cell having straining boxes intervening to collect small particles of cush-cush or megass, that may be retained in the juice, the delivery side of the pump connected to the top of the diffusion vessel having heaters intervening between the pump and the diffusion vessel to bring the juice to the required temperature."

As applied to the cane sugar industry the process, while including the system of forced circulation, has come to imply a combination of milling and diffusion, with simultaneous liming, clarification and filtration.

In the process as erected in quite a number of factories the canes are dry crushed in a six-roller mill, an extraction of about 70 per cent. of weight of juice on canes carrying 12 per cent. of fibre being obtained. A cell of the diffusion battery being filled with the megass resulting from the dry crushing of the canes, a quantity of juice corresponding to the megass in the cell is allowed to enter. The cell is then filled with more dilute juice obtained from the diffusion of a previous lot of megass; from this cell is taken the charge of diluted juice that passes on to the boiling house, the circulation of the juice

Fig. 140.

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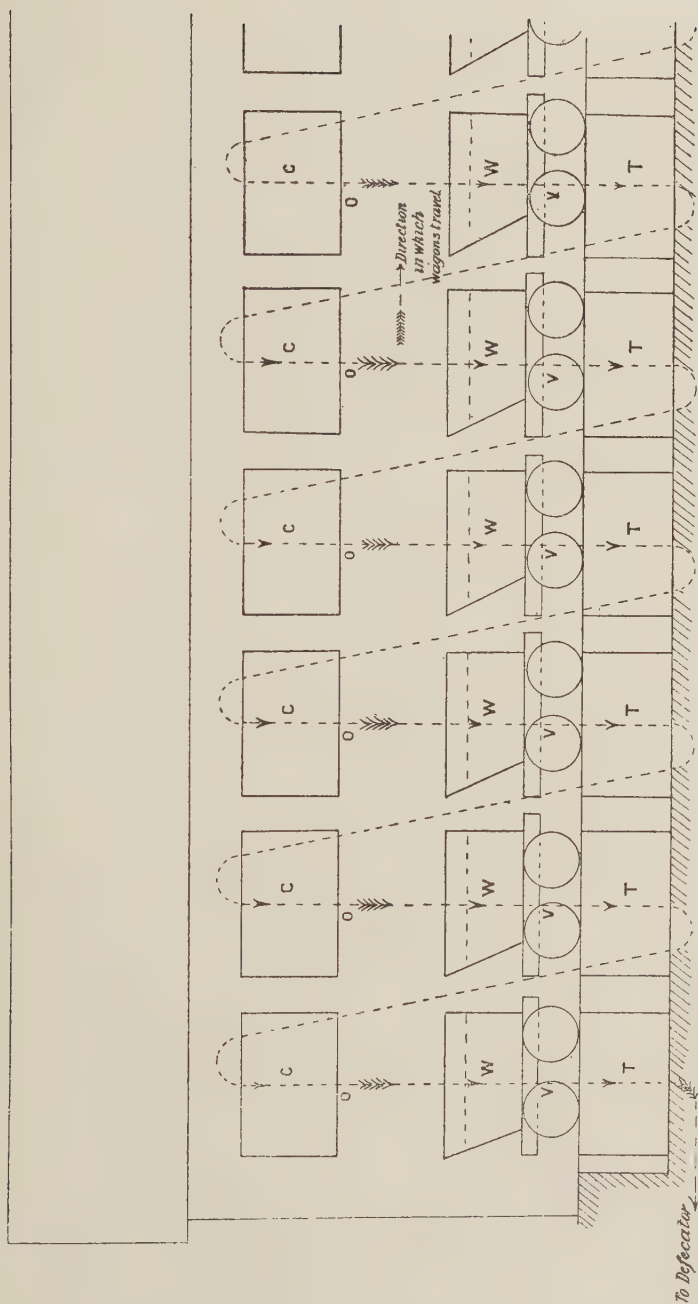
being conducted in the manner prescribed in the Naudet patent. After the withdrawal of the charge of juice, the megass remaining in the cell passes through the usual process of exhaustion in the diffusion battery; when finally exhausted it is discharged and passed through a mill for use as fuel.

Comallonga[6] gives details of the installation and results obtained at San Jose in Cuba. The cane worked up was 1000 tons per 24 hours; there were 10 diffusers of a capacity of 70 hectolitres (246 cubic feet) each; there were three cells always out of circuit, filling or emptying, so that the megass went through a seven-fold diffusion; per 100 kilos of cane, the charge of juice withdrawn was 92-93 litres; the temperature maintained in the battery was 95–100° C.

With canes, containing 13·06 per cent. of sugar, the loss in megass was ·89 per 100 cane, corresponding to an extraction of 93·19 per cent.

In the Naudet process, the juice passes directly from the diffusion battery to the evaporators, the liming being done in the battery, and owing to the filtration of the juice through the megass, the clarifiers and filter presses are dispensed with; notwithstanding this, Comallonga states that, owing to the extra number of hands required at the battery, the process does not show any saving in labour.

At the time of writing (1910) the Naudet process not only does not extend, but some factories that had adopted it have reverted to multiple milling, and figures supplied to the writer do not show any superiority to those obtained from an average nine-roller mill.

In justice to this process, it should however be mentioned that the inventor claims that in at least one case where the process was abandoned the failure was due to incompetence and to the alteration of his original designs; in Madeira, where the process was first applied to the cane, a continued success is claimed.

Geerligs-Hamakers Process[7].—In 1903, Geerligs and Hamakers demonstrated by large scale experiments in Java, that by diffusing megass from a six-roller mill and crusher, an extraction of 98 per cent. was obtainable with a dilution of 19·6 per cent. on normal juice. This scheme has not been adopted, but in the writer's opinion, this process, or one based on similar grounds, is the only one likely to supersede multiple milling as a means of sugar extraction from canes.

REFERENCES IN CHAPTER XII.

1. Spencer's *Handbook for Sugar Manufacturers.*
2. *Overseer's Manual.*
3. *S. C.,* 199.
4. *I. S. J.,* 45.
5. *S. C.,* 346.
6. *Bull. de Soc. Agric. Cuba,* iii. 2.
7. *I. S. J.,* 60.

CHAPTER XIII.

THE CLARIFICATION OR DEFECATION OF THE JUICE.

The object of clarification is to remove from the juice, as far as possible, all bodies other than sugar, to obtain a juice permitting of easy filtration and working in the pans and centrifugals, and when making sugars intended for direct consumption, to obtain a bright, light-coloured, transparent juice.

In rough outline, the processes in use are as below :—

1. The juice is raised to a temperature of about 190° F. to 200° F. by being passed through a juice heater (*see below*); it is then received into tanks of 500 gallons' capacity and upwards, where it is allowed to settle for varying times dependent upon the capacity of the clarifiers in relation to volume of juice; after half-an-hour's settling a fairly clear juice can be drawn off above a deposit of dirt and precipitated matter; this juice is sufficiently clarified to be passed direct to the evaporators when dark crystals are being made.

2. The fairly clear juice obtained as in 1 is passed on to vessels known as eliminators; these are rectangular tanks of depth from 3 to 3½ feet, and about 8 feet by 6 feet in length and breadth; at the bottom is placed a trunnion pipe into which are fitted brass or copper tubes through which steam is passed for the purpose of heating the juice. An allowance of 1 square foot heating surface for every 3 to 4 gallons capacity is usually found. Round the top edge of the tank is arranged a gutter; the juice is boiled in these tanks with the object of bringing the suspended impurities to the surface, whence they are brushed into the gutter and passed on to the filter presses; very clear juices can be obtained by this method, which is however most wasteful of steam.

3. The juice, either after passing through the juice heater, or when cold, is received into tanks provided with a heating surface similar to the one described in 2; the heating surface sometimes takes the form of a coil, or the tank may have a steam jacket. The juice is kept in these tanks at a temperature of about 205° F. ; at this temperature the heavier particles of dirt subside, and a lighter äerated scum rises to the surface; between these layers is the bulk of the juice, clear and transparent. Many factories in Mauritius make high-class, white, consumption sugars with these clarifiers alone.

4. Any of the above processes may be used, followed by a bulk filtration of the juice.

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5. In Mauritius a peculiar apparatus known as a *Bac Portal* (*Fig. 141*) is frequently used; this consists of a shallow tank about 1 foot deep, and about 15 feet in length and breadth; the tank is divided into compartments about 1 foot wide by divisions parallel to the sides; at alternate ends of these divisions the partition is cut away to a depth of 1 inch, and to a length of 1 foot; juice being admitted to the tank at one corner fills the compartment, overflows at the far end, changes its direction, fills the next compartment, again overflows, and so on. The juice has to travel in this way a distance of about 200 feet, and during all that time it is depositing the suspended dirt. One apparatus will work continuously for twelve hours, and give a fairly bright and clear juice, but not comparable with filtered juice.

6. In Australia[1] a continuous clarifier is in use. It consists of a cylindrical vessel about six feet high, mounted on a conical vessel also about six feet deep. The clarifier is capable of holding an hour's output of the mills, so that the dimensions become very large. The juice is introduced by a pipe which passes over the side of the vessel, and divides at the junction of the cone and cylinder into eight branches, the juice being projected against the

Elevation of Partition Plate
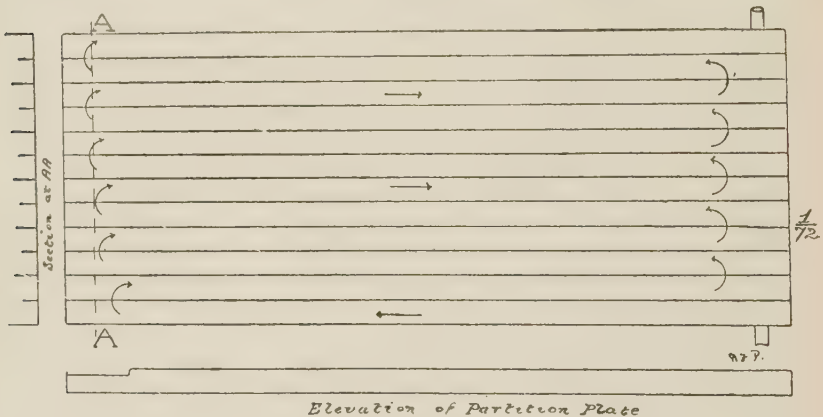
FIG. 141.

sides of the cone. As the vessel fills there is a very slow upward movement of juice, the dirt having time to settle. A gutter runs round the upper edge of the cylinder, into which the clear juice flows, the dirt depositing on the sides of the cone. Periodically this dirt is scraped off and the accumulated deposit discharged without interrupting the working of the apparatus.

7. In San Domingo[1] the cold limed juice is introduced at the bottom of a double-bottomed clarifier. Within the latter is arranged a cylinder reaching to within six inches of the bottom and to within twelve inches of the clarifier. The short leg of a syphon reaching nearly to the bottom is placed within the cylinder and serves to continuously draw off the juice. The juice is kept at a temperature of 208–210° F., at which temperature the scums rise to the

surface and are removed without breaking them up. The temperature is kept constant by an ingenious thermostatic device ; cold water circulates in a coil of copper following the curve at the bottom of the clarifier. As this water is heated it expands, and when the temperature becomes too great the expansion operates the lever of a throttle valve admitting steam to the double bottom and shuts off the supply.

8. A type of automatic clarifier due to Hatton[2] is shown in *Fig. 142*. The cold limed juice flows through the pipe *a* and the regulating valve *b*, entering the defecator by the pipe *c*. As the defecator fills up, the juice overflows and fills the vessel *d*, which is closed at the bottom; hence the juice
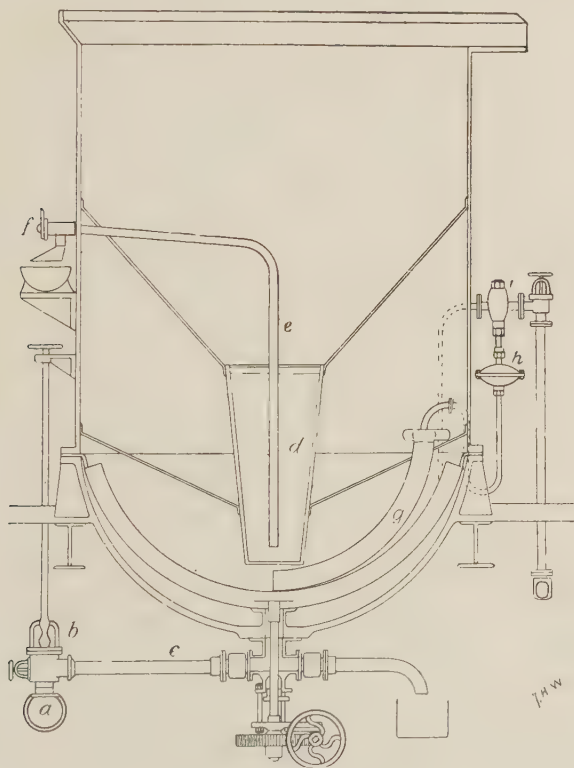
Fɪɢ. 142.

passes upwards through the pipe *e* and away by the pipe *f* into the clear juice conduit and thence to the evaporators.

The scums collect on the surface of the juice and are removed from time to time ; it is claimed that these contain so little sugar that filter pressing is unnecessary. The heat necessary is obtained by passing steam into the double bottom ; heavier particles which settle are disturbed by occasionally rotating the scraper and are then stated to be carried upwards to the floating layer of precipitated material. The amount of steam entering, and consequently the

temperature of the juice is self-controlled by a thermostat ; at g is shown a tube filled with water ; the expansion and contraction of the water acts on a diaphragm in the regulator h and thereby operates the balanced valve at i.

Juice Heater.—A juice heater, *Fig. 143*, consists of a vertical or horizontal cylindrical cast iron body.

At the upper and lower ends are placed tube plates which carry the tubes within which the juice circulates, low pressure steam enters at a, the condensed water is collected at c, the juice enters at b, and is caused to change its
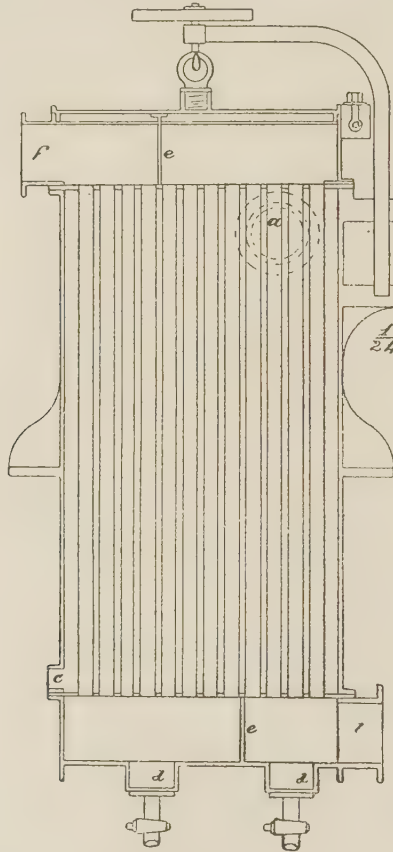
Fig. 143.

direction twice by the partition plates at e, passing out at f; at d are shown scum cocks for emptying the vessel after cleaning.

As a rough rule, for every five gallons of juice per hour, one square foot of heating surface is required.

Instead of heating the juice with back pressure steam from the engines, juice heaters are sometimes attached as surface condensers to the last body of the multiple effect evaporator. Where a good vacuum in the last body is

maintained, the juice may be heated to a maximum temperature of no more than 130° F., the further rise in temperature required being obtained by a juice heater as described above.

The method whereby juices are heated with *extra steam* taken from the evaporators is described in a subsequent chapter.

Determination of Lime required for Clarification.—The lime is usually applied as a cream standing about 20°–25° Brix, the quantity required being determined by one of three methods :—

1. The raw juice is tested in the laboratory, and from the result the amount of lime required per clarifier is obtained. When working on these lines frequent tests should be made.

2. To a clarifier half full of juice an amount of lime approximately that which experience has shown to be necessary is added, and the reaction of the limed juice to litmus paper observed. According to the reaction the same, more, or less lime is added when the clarifier is full. Working in this way the proper amount of lime required for a clarifier is soon found.

3. Instead of using litmus paper, the limed juice is filtered into a test tube, and to the clear filtrate a drop of a solution of lime in sugar is added. The formation of a precipitate indicates the necessity for more lime, no precipitate occurring with an overlimed or exactly tempered juice.

These three methods do not give consonant results, for a juice limed so far as to be just alkaline to litmus will give a further precipitation on the addition of more lime; precipitation being only complete in the presence of a considerable excess of lime.

The writer is inclined to regard clarification rather as a craft or art than as a science, and pays attention to the following points :—

1. Enough lime must be used to give a faint alkaline reaction to litmus.

2. The precipitate must settle readily.

3. No more lime should be used than will satisfy the above requirements.

In the writer's opinion the best control is to place a sample of the juice from each tank in a four-ounce bottle, and to place each sample on a table convenient for the observation of the *employé* responsible, who is guided by the reaction and the colour of the juice and by the setting of the precipitate.

Choice of Lime.—The lime used should be as pure as possible; the objectionable constituents that occur in limestones are silica, alumina, magnesia and sulphate of lime. The first two, if present in limestone, may form a coating over the lime and prevent it slaking properly. Magnesia and sulphate of lime are particularly objectionable, as when introduced into the juice they are deposited, on concentration, on the tubes of the evaporators as scale. Two per cent. of magnesia should be the highest quantity allowable in a lime intended for use in a sugar factory.

Below are given analyses of limestones, after Gallois & Dupont[3], classed by them as bad, passable and excellent :—

Material.	Bad.	Passable.	Excellent.
Moisture	4·10	6·25	1·21
Sand, clay, and insoluble matter	4·50	3·17	0·55
Organic matter	1·20	1·12	0·41
Soluble silica	2·10	0·64	0·20
Oxides of iron and alumina	0·37	0·15	0·23
Calcium carbonate (limestone)	85·86	87·93	96·58
Magnesium carbonate	0·95	0·53	0·50
Soda and potash	0·05	..	..
Undetermined	0·87	0·24	0·32

The Effect of Lime in Clarification.—The effect of lime and heat on cane juice is

1. Some proteid and gummy matters are precipitated; generally speaking the greater the amount of gums originally present, the greater is the percentage of gums precipitated.

2. Earthy phosphates and bases of all metals except the alkalies are precipitated.

3. Mechanical impurities, as wax, fibre, &c., are entangled and caught in the proteid and gum precipitate.

4. The juice is made capable of filtration.

5. With an excess of lime reducing sugars are decomposed into organic acids; this action is discussed in the following chapter.

6. The purity of the juice is elevated up to a maximum of three to four units.

The nitrogenous precipitate obtained by the action of lime consists entirely of albuminoids; xanthine bases and amides are not precipitated by lime, and as amides are present chiefly in unripe cane it is in such cane that the nitrogenous matter chiefly passes on to the after products of the factory. In general, with lime clarification the writer's opinion is that the best results are obtained with a juice very slightly alkaline, sensitive litmus paper being used as an indicator, and, although considerable difference of opinion exists, he does not place reliance on the value of phenolphthalein as a criterion to show at what point the addition of lime should cease. It is with juices containing a high proportion of reducing sugars that an excess of lime is most harmful, and its evil effects are reflected through the whole course of manufacture, in low masse cuites hard to purge, in viscous molasses, and in low sugars, dark coloured and of low test; with juices containing little reducing sugar, an excess of lime is not detrimental.

Effect of Alkalies on Reducing Sugar.—The action of large quantities of alkalies on reducing sugars is discussed in the next chapter. As shown originally by Lobry de Bruyn and van Ekenstein[4], reducing sugars, when heated with small quantities of alkalies, suffer isomeric change; dependent on the conditions of experiment, dextrose and levulose are mutually convertible into each other; in addition, mannose, and a sugar to which the name glutose[5] has been given, are also formed. Mannose is formed in only small quantity, but the prolonged action of alkalies on the naturally present reducing sugars of the cane results in the formation of considerable quantities of glutose; this body is unfermentable, its reducing power is half that of invert sugar, and it may account for the unfermentable reducing residue found after fermenting molasses with yeast. In cane juices the dextrose is always in excess of the levulose, but in molasses due to this isomeric change a reversal of this order may happen.

This isomeric change also takes place under the influence of the alkali salts of weak acids, such as sodium acetate.

The Use of Sulphur.—After lime the agent that has been most used in clarification, and one the real effect of which is but little known, is sulphur, in the form of sulphurous acid or sulphur dioxide. Various apparatus are in use for impregnating juices with sulphurous acid, of which three forms are illustrated below.
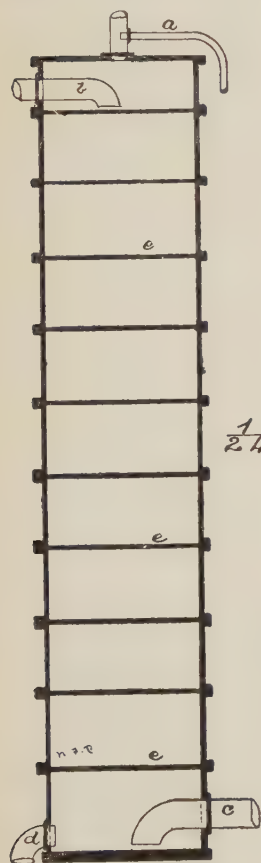
The '*sulphuring*' is often performed in the apparatus shown in *Fig. 144*. It consists in general of an upright vertical chamber, about twelve feet high, constructed of wood. At every foot or so horizontal perforated plates e, or some other device calculated to throw the juice into a shower, are fitted. The sulphur fumes enter the box at the bottom, being led by the pipe c from the oven where the sulphur is burnt. The juice enters the sulphur box at the top of b, and falling down in a fine shower passes out at d. An upward draught is created in the sulphur box by allowing a jet of steam to exhaust through the pipe a.

In *Fig. 145* is given a view of a more detailed scheme; an air compressor or pump b forces the air necessary for combustion first through the vessel d, packed with quicklime, and thence to the ovens a. The rate at which the sulphur burns is controlled by the speed of the pump or compressor. Above a

FIG 144.

is a column c, provided with trays packed with chalk, serving to filter the gas and to retain sulphuric acid. The upper surface of the oven is made double, so that cold water circulation may cause the condensation of sulphur volatilized. The sulphur dioxide passes along the pipe f, whence it reaches the bottom of the sulphitation tanks, being evenly distributed by means of a perforated coil. The ovens a are provided with doors, through which the sulphur is introduced, contained in a basket. So as to be continuous in action, the ovens are worked alternately.

Another method, and one which in the writer's opinion is reliable and easy of control, is shown in *Fig. 146*.

The sulphur is burned in the iron pot a, being introduced therein, in quantities of about one pound at a time, through the aperture b, which may be kept closed by a tight fitting movable lid. The air necessary for combustion passes through the pipe c, which is filled with lumps of quicklime, which are renewed daily. The draught and pressure necessary to force the sulphur gas into the juice are obtained by the injector shown at e, working at not less
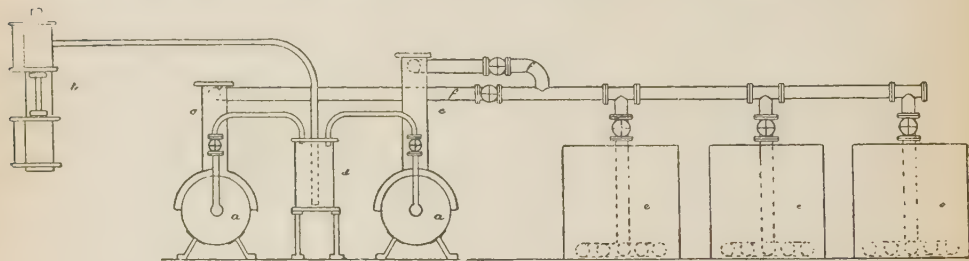
FIG. 145.

than 60 lbs. pressure per square inch; parts of this exposed to the action of the gas are made of a lead-antimony alloy containing about five per cent. of antimony.

The use of sulphur is very old; it was originally used by Melsens, in 1810, and there is probably no subject connected with the sugar industry about which so much has been written, and about which so little is actually known. What is claimed to occur may be briefly summarized.

1. Juices are easier to filter.

2. Masse cuites ' work better ' in the pan, and are easier to purge, owing to a decrease in viscosity.

3. A greater precipitation of impurities occurs.

4. Juices are bleached.

In so far as regards the bleaching action of sulphurous acid, it may be remarked that any acid gives a light coloured juice; Maxwell[6], however, has shown that sugar solutions coloured artificially by prolonged heating with acids are completely decolourized by sulphurous acid.

In experiments made by the writer limed juices and limed and sulphured juices exactly duplicating factory conditions gave the same weight of precipitate, and the writer does not believe that it can be claimed that sulphuring gives an increase to the purity of the juice above that due to the juice of lime. Very different methods of sulphuring juices are in vogue; in Louisiana it is usual to sulphur the cold juice until the acidity is from 3 c.c. to 5 c.c. $N/10$ acid per 10 c.c. of juice; lime is then added until the juice is very slightly acid. In Java, according to Prinsen Geerligs, the raw juice is limed with about twice as much lime as is indicated as necessary by the saccharate of lime test (*supra*); afterwards the juice is sulphured until only a faint red colouration is afforded by phenolpthalein. In Mauritius, where white sugars are made, it is general to sulphur first and lime afterwards, but in Demerara, in the manufacture of Demerara crystals, the juice is generally limed before sulphuring.
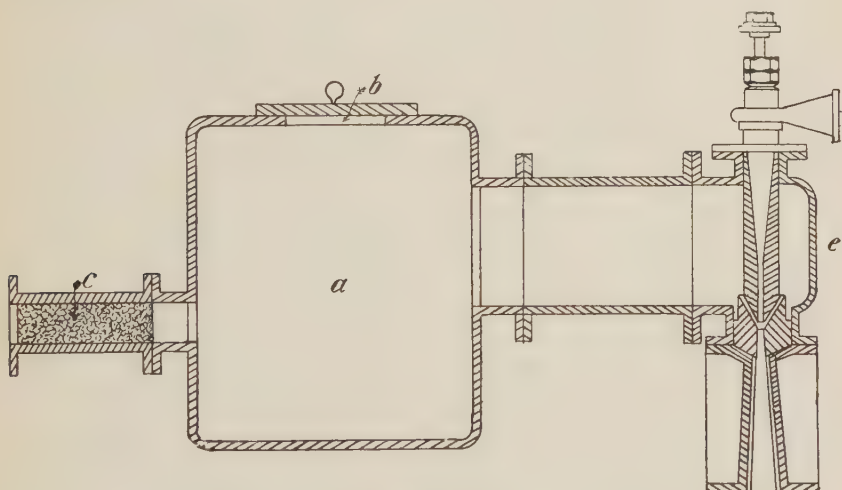
Fig. 146.

In the writer's opinion it is not of much moment whether lime or sulphur be used first, as long as the following points are observed :—

1. Heat should not be applied to a juice in the presence of a notable excess of either reagent.

2. The result of the combined treatment should be to obtain a juice almost exactly neutral.

In burning sulphur it is of great importance that the air be dry, else a part of the sulphur burns to sulphuric acid, which not only is of no use but is a cause of the deposit of scale and of the corrosion of the valve seatings in the vacuum pumps.

Two classes of sulphites exist, both of which may be present in limed and sulphured juice : the normal neutral sulphites of the formula M_2SO_3

and the acid bisulphites of the formula $MHSO_3$. These two forms react differently with litmus and phenolphthalein, the most generally used indicators in the sugar house. Soluble sulphites react neutral with phenolphthalein, but alkaline with litmus; hence when a sulphured juice reacts neutral to phenolphthalein the normal sulphite is present, and such a juice may give an alkaline reaction with litmus; when a juice reacts acid with litmus, then bisulphites are present. A distinction beween the two classes of sulphites is that the normal calcium sulphite is insoluble, the bisulphite being soluble; if, then, a juice is sulphured in such a way that bisulphites are present, these remain in solution; in the evaporator they become decomposed into SO_2 and the normal sulphite; the former on oxidation accounts for the presence of sulphuric acid in calandria water, and the latter also oxidizing appears as a scale of calcium sulphate on the tubes of the evaporators.

Use of Phosphoric Acid.—A third agent employed as a clarificant in more or less general use is phosphoric acid appearing under various trade names as ' Clariphos,' ' Ehrmanite.' It is used to counteract the effects of an over application of lime, and also as an actual precipitant of non-sugar. If a solution of phosphoric acid be added to a limed juice, the first effect is to produce a precipitate of calcium phosphate; if this precipitate be collected it will be found to contain a notable percentage of organic matter; if, however, the addition of phosphoric acid be continued, a soluble superphosphate of lime is formed, and the original precipitate redissolves.

Oxalic Acid.—This body has also been, and sometimes is, used in a similar way, and the precipitate of calcium oxalate, which does not redissolve on adding an excess of oxalic acid, also contains a notable quantity of organic matter.

Carbonate of Soda.—An excess of lime salts has the property of making the molasses very viscid, and in some factories it is the practice to clarify with lime and soda, using the latter to neutralize the natural acidity of the juice, and the lime to effect precipitation of the albumenoids.

Other Agents Proposed for Clarification.—Upwards of six hundred agents and combinations of agents have been proposed for use in clarification; they fall into two main classes, those that aim at a discoloration of the juices and those that are intended to remove non-sugars from the juices. The removal of non-sugars is often attempted by the precipitation within the solution of a bulky precipitate, such as of alumina, phosphate of lime. The proposed agents may be classified thus :—

1. Sulphur compounds, including sulphurous acid, soluble sulphites and bisulphites, including those of the alkalies, alkaline earths, aluminium and iron, hydrosulphites of soda and of lime.

2. Phosphoric acid and soluble phosphates and acid phosphates of the alkalies and alkaline earths and of aluminium.

3. Salts of aluminium in combination with bodies designed to produce a precipitate of alumina, and including the aluminates of the alkalies and of the alkaline earths; the precipitation of alumina within a sugar solution whether from an alum or aluminate produces a notable clearing of the solution and the carrying down of much colloid matter, but the writer is of the opinion that the value of the amount of material required is greater than the benefit to be obtained, in addition to the difficulty of handling the very bulky gelatinous precipitate formed.

4. Salts of the heavy metals, especially of lead, zinc and tin. All of these produce copious precipitates, but their poisonous nature is an insuperable obstacle to their use.

5. Baryta and its salts, and in combination with other agents. Baryta is certainly a powerful clarifying agent, but its poisonous nature, as well as the expense involved, prevents its use.

6. Agents designed to the removal of potash, including the use of fluosilicic acid and its salts, and filtration through layers of calcium aluminium silicates.

7. Unclassified agents, including ozone, chlorine, hypochlorous acid, hydrofluoric acid, permanganate of potash, chromic acid, tannic acid often suggested to be used in combination with aluminum salts, oxalic acid in combination with lime, clay, brick dust, oils, kieselguhr, albumen.

8. Electrical processes.

Of later processes that have been proposed may be cited those of Ranson[7], which include the use of zinc, tin, hydrosulphurous acid, hydrogen peroxide, and aims at a decoloration of the juice and direct manufacture of white sugar by alternate oxidations and reductions. Gans[8] proposes the use of artificial zeolites or calcium aluminium silicates as a filtering material, whereby the potash of the juices is replaced by lime; this material was placed on the market under the name of 'Permutit,' but Claassen[9], who examined its action, found that, although the potash could be thus removed, the viscosity of the resulting material due to the substituted lime salts was much increased, and he was unable to recommend its use. Hlavati[10] proposes the removal of potash by means of fluosilicic acid, and Besson[11] employs powdered aluminium alloys in an alkaline juice to obtain a precipitation of alumina and decoloration through the agency of the hydrogen evolved. When this plan is used in the juice in the evaporation, a diminution of the deposit of scale and an increased transmission of heat is claimed.

A detailed list of the various proposals has been given by von Lippmann[12].

Clarification for White and Yellow Sugars.—The clarification of juices for the manufacture of these sugars differs from that used when making refining crystals in that the action of sulphurous acid is essential, and that juices are boiled with a slight acid reaction; in addition much greater care is taken to remove suspended and floating foreign matter from the juices.

In Demerara the process followed is as under:

The raw juice is limed cold and sulphured generally in a 'sulphur tower,' *Fig. 144,* the appearance of the juice—very pale yellow—forming a guide to the operator of the efficacy of the treatment; the juice now has an acidity of about 5 c.c. – 7 c.c. N/10 acid per 100 c.c. of juice, phenolphthalein being used as indicator. After passing through a heater and settling, the partially clarified juice is run into vessels of about 1000 gallons gross capacity in which are arranged steam coils; around the edge of these vessels is arranged a gutter. These vessels are known as eliminators; the juice is made to boil, and the scum that rises to the surface is brushed off with wooden tools into the gutter; to the juice in the eliminators phosphoric acid is added, the acidity now lying from 12 c.c. – 20 c.c. N/10 acid per 100 c.c. of juice. This method of cleaning juices is most thermophagous, and at best much inferior to the effect obtained by the use of mechanical or sand filters; results quite equal to those obtained by eliminators may be obtained by straining the juice through fine copper gauze of 120 meshes per linear inch. In the manufacture of white sugars in Mauritius a similar process is followed, except that the acidity of the finally tempered juice is considerably less, and is about 8 – 12 c.c. N/10 acid per 100 c.c. of juice.

In the writer's opinion the manufacture of fancy sugars is largely a question of the acidity of juice in connection with the colour reactions of cane juice, which, having an important bearing on the matter, may be mentioned here.

Use of Hydrosulphite.—About 1904 the manufacture of staple hydrosulphites became possible, and they were introduced into the dye industry, and thence, as decolorizing agents, into the sugar industry. The sodium salt appears under the trade name of ' Blankit,' and the calcium salt under that of ' Redos.'

Hydrosulphites are very powerful reducing agents, and act under the equation

$$Na_2S_2O_4 + O + H_2O = 2NaHSO_3.$$

In the cane sugar industry they find an application in the bleaching of juices and syrups in the manufacture of direct consumption sugars.

In connection with their use it has been observed that after juices and syrups have been bleached they become darkened on exposure, and it is usual to introduce the hydrosulphite dry into the vacuum pan. A quantity of

hydrosulphite required to obtain the maximum bleaching effect found by the writer was one pound per ton of sugar, but the quantity necessary has to be determined by trial and error, and a much less quantity is stated to be required by the makers of this compound.

Hydrosulphite has no effect on the dark coloured products obtained on overheating sugar juices, and the specific effect claimed for it in reducing viscosity hardly seems possible when the small quantity used is borne in mind.

The Colour Reactions of Cane Juice.—The colour reactions of cane juice having an important bearing on the manufacture of direct consumption sugar may be mentioned here. In the presence of an excess of alkali, filtered cane juice is of a golden yellow colour; if the alkali be gradually neutralized with an acid a point is reached where the golden yellow colour turns to an olive brown; the addition of the acid being continued, the cane juice finally becomes almost colourless. When in the intermediate olive brown zone, the juice is almost exactly neutral. The colour reactions of cane juice as described above are exemplified in the following experiment :—

To 100 c.c. of clarified almost neutral cane juice, exactly sufficient normal caustic soda was added to develop the golden yellow tint, the quantity found necessary to be added being 1 c.c. To 100 c.c. of the cane juice thus treated normal sulphuric acid was added and the changes in colour observed; the different juices were kept at a temperature of 95° C. for half-an-hour, so as to determine at what point appreciable inversion (see below) set in. The details of an experiment are given below.

100 c.c. of clarified cane juice treated with 1 c.c. normal caustic soda developed maximum yellow colouration.

c.c. normal acid added per 100 c.c. of prepared juice.		Colour.		Reaction.		Polarization after heating to 95° C, for half-an-hour.
·0	....	Golden Yellow	....	Alkaline	....	58·1
·4	...	,,	....	,,	....	58·0
·8	....	,,	....	,,	....	58·1
·9 ⎱	....	⎰ Intermediate	....	Neutral	....	58·0
1·2 ⎰	....	⎱ Olive brown zone	...	,,	....	58·0
1·4	....	Light	....	Acid	....	58·1
2·0	....	,,	....	,,	....	58·0
2·2	....	,,	....	,,	....	57·0
2·6	....	,,	....	,,	....	49·0

It was not until there was an excess of normal sulphuric acid of 1 c.c. per 100 c.c. of juice over and above the neutral intermediate zone that inversion was detected.

In *Sugar and the Sugar Cane* the author expressed himself thus : " This is thus the limit which the manufacturer can allow himself when making

consumption sugars without danger of inversion." This reasoning was, however, incorrect, for the invertive action is profoundly modified by the large amount of neutral salt present in the experiment and which does not occur in the boiling-house; also the acids used in the boiling-house—sulphurous and phosphoric—have in any case a much less pronounced action than sulphuric. Actually, however, juices with an acidity due to phosphoric acid equal to a maximum of 20 c.c. decinormal acid per 100 c.c. of juice are worked in the manufacture of consumption sugars.

Indicators.—By an indicator is meant a body which by a change of colour indicates the end point of some chemical reaction, and in the sugar house it is used to indicate the acidity or alkalinity of the juice. The two indicators most extensively employed are litmus and phenolphthalein; the former is red in acid and blue in alkaline solution; the latter, colourless and crimson. A difference in the indication of these bodies with lime and in the presence of sulphites has already been noted, and the question, which is the most reliable indicator to use, is one which is constantly recurring. This is really largely a question of the glucose content of the juice; phenolphthalein does not give an alkaline reaction until there is present considerably more lime than is required to give an alkaline reaction with litmus; if juices such as are common in Demerara, containing from 1·5 per cent. to 2 per cent. of glucose were limed till they gave an alkaline reaction with phenolphthalein, serious trouble, due to the action of the lime on the glucose, would result; juices with less glucose will be able to take a larger amount of lime and obtain a greater precipitation of non-sugar without injury.

In saturating alkaline juices with sulphurous acid it must be remembered that litmus reacts alkaline to acid sulphites and hence phenolphthalein is the more suitable indicator.

Phenolphthalein is exclusively used in the beet sugar industry, but conditions are dissimilar and Pellet in particular has frequently insisted that litmus is the most general cane sugar indicator.

An indicator of some little use is a reagent consisting of equal parts of methyl orange and rosolic acid in alcoholic solution; this reagent becomes a peculiar port-wine red in the presence of bisulphites, but in general the colour of cane products is so pronounced as to mask the appearance of this colour. The colouring matter of cane juice itself forms an indicator of no inconsiderable value, and is discussed above.

Speaking generally, the appearance of the juice viewed in a tall glass makes a valuable criterion, a clear hock-coloured juice with a rapidly settling precipitate being the appearance to be looked for; the condition of the press cake is also a guide, soft sloppy cakes being often the result of too little lime.

Inversion.—Cane sugar, under the influence of acids, is quantitatively converted into dextrose and levulose under the equation

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

Cane Sugar   Water   Dextrose   Levulose
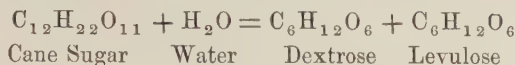
Under the ionic hypothesis an acid in solution is conceived as being in part dissociated into hydrogen ions and into acid-radical ions; thus hydrochloric acid in solution is taken as consisting of undissociated HCl, and of H ions, and of Cl ions, the former carrying a + and the latter a — charge of electricity. The inversion of cane sugar under the same hypothesis, and, indeed, all the particular properties of an acid, are held to be due to the hydrogen ions. A strong acid is one which is largely, and a weak acid is one which is slightly, dissociated. The chief laws under which the inversion of cane sugar proceeds are summarized below.

1. *Rate of Inversion.*—When all other conditions are unchanged, the rate of inversion is proportional to the active mass, *i.e.*, when the temperature and the concentration of the acid are unchanged, a 20 per cent. solution of cane sugar inverts twice as fast as a 10 per cent. solution. Developed mathematically, this statement becomes reduced to the following form :—

In a sugar solution let there be a parts of sugar present; in a small interval of time, t, let x parts be inverted. There are now present $a-x$ parts of cane sugar. Since the rate of change is proportional to the active mass,

$$\frac{d\,x}{d\,t} = k\,(a-x) \text{ where } k \text{ is a constant.}$$

Whence, by integration $\qquad \log.\ \dfrac{a}{a-x} = k\,t$

or $\qquad \dfrac{l}{t}\,\log.\ \dfrac{a}{a-x} = k$

The constant k gives a means of comparing the strength of different acids, or, under the ionic hypothesis, the degree of dissociation. This law was found experimentally by Wilhelmy in 1850, and developed on *a priori* reasoning by Guldberg and Waage in 1867. It forms a typical instance of the universal law that rate of chemical change is proportional to the active mass.

As definitely applied to a sugar solution in acid medium, let the total change in polarization due to inversion be a; then a is proportional to the amount of sugar originally present. Let the fall in polarization, *i.e.*, the algebraical difference between the initial reading and the reading after any time interval, t, be x; then x is proportional to the amount of sugar inverted. The calculation of the constant will then appear as in the following example.

Initial reading, 40°; reading after complete inversion, — 12°; total change $= a = 52°$; reading after 60 minutes, 30°; proportionate amount of sugar inverted $= x = 40 - 30 = 10$. Then

$$\text{Constant} = \frac{1}{60}\log.\ \frac{52}{52-10} = \cdot001546.$$

2. *Influence of Acid.*—The constant k was determined by Ostwald[13] in 1884, for a large number of acids; some values as found by him are given below. These are referred to half normal strength, to 25° C. temperature, the time being expressed in minutes, and the logarithms being common ones.

Acid.	Constant.	Acid.	Constant.
Hydrobromic..	·002187	Sulphurous	·0006630
Hydrochloric	·002438	Oxalic	·0004000
Nitric	·002187	Phosphoric	·0001357
Sulphuric	·001172	Acetic	·0000088

3. *Effect of Concentration of Acid.*—Within comparatively narrow limits the rate of inversion is nearly directly proportional to the concentration of the acid. With the stronger acids, however, the rate of inversion decreases more rapidly than does the decrease in concentration; with weaker acids, the reverse holds.

4. *Effect of Temperature.*—The following empirical equation, due to Urech,[14] connects velocity of inversion and temperature:—

$$C_1 = C_0 \cdot e^{\frac{A\,(T_1\,T_0)}{T_0\,T_1}}$$

where C_0 and C_1 are the rates of inversion at T_0 and T_1, e is the base of the natural system of logarithms, and A is a constant, and equal to 12820. Putting the rate of inversion at $25°\,C. = 1$, this expression gives the following rates of inversion at the stated temperatures :—

°C.	Rate.	°C.	Rate.	°C.	Rate.
25	1	60	91·8	85	1354
40	7·6	65	162	90	2110
45	14·3	70	282	95	3573
50	26·7	75	483	100	5659
55	57·7	80	814		

The Effect of Neutral Salts.—It was originally shown by Arrhenius[15] that the rate of inversion by acids was accelerated by the presence of the halides and nitrates of the alkalies and alkaline earths. The writer[16] has extended his observations, and has found :—

1. In concentration up to ·02 N at 100° C., the halides and nitrates have an inappreciable effect on the rate of inversion with very dilute acids.

2. Under similar conditions the sulphates, sulphites, oxalates, and all alkali and alkaline earth salts of weaker acids retard inversion.

3. In concentration of acid and salt of the normal order, at ordinary temperatures, the halides and nitrates of the alkalies and alkaline earths accelerate the rate of inversion; the acceleration increases progressively from chloride to bromide, to iodide, the effect of nitrates being similar to that of chlorides. A difference in the base of the salt has very little, if any, effect; thus, the acceleration due to sodium chloride is substantially the same as that due to calcium chloride.

FIG. 17.
PORT
MACKAY.

$\frac{3}{4}$
SIZE

PLATE XVI

4. Under similar conditions, sulphates, sulphites, oxalates, &c., retard the rate of inversion.

Effect of Glucose.—The action of glucose on the inversion of cane sugar is a peculiar subject, some investigators finding that glucose of itself caused inversion, and others observing no effect. Geerligs[17], in investigating the subject, came to the conclusion that glucose of itself had no invertive action, but that in the presence of neutral salts, such as chlorides, nitrates and sulphates of the alkalies and alkaline earths, inversion occurred at the temperature of boiling water, owing to a slight hydrolysis of the neutral salt under the influence of the glucose. The writer[16] in investigating the same subject failed to obtain any trace of inversion due to the combined influence of glucose and neutral salts, when the latter were present in normal concentration.*

Inversion under Acid Salts.—Salts of the heavy metals, such as zinc sulphate, also cause the inversion of cane sugar. This has been chiefly studied by Long[18]; the inversion is ascribed to the partial hydrolysis of the salt, thereby affording free hydrogen ions in solution.

Inversion under the Influence of Enzymes.—Besides chemical inversion under the influence of acids and acids salts, cane sugar is inverted by the action of certain ferments known collectively as enzymes. The enzyme most studied is that secreted by yeast, and known as invertase. The properties of this body were first investigated by O'Sullivan and Thompson[19], who found that the most favourable concentration of the sugar solution was 20 per cent., that the *optimum temperature* was 55° C. to 60° C., the enzyme being slowly destroyed at 65° C., and instantaneously at 75° C. The action of invertase is greatly accelerated by minute traces of acids. O'Sullivan and Thompson found that the law of mass action held for the action of invertase, a result not obtained by subsequent workers until C. S. Hudson[21] showed that these had neglected to take into account the mutarotation of the invert sugar formed.

Another instance of enzyme inversion of interest to the sugar industry was examined by Lewton-Brain[22]; he found that the fungus connected with the Red Rot of the Stem (*Colletotrichum falcatum*) secreted an invertase capable of rapid inversion of cane sugar.

Inversion and Manufacture of Consumption Sugars.—

It has already been stated that in the manufacture of consumption sugars it is customary to work juices with an acidity reaching up to 20 c.c. decinormal acid per 100 c.c. of juice. Sugar and water, even with acetic acid, at such an acidity, would be very rapidly inverted at 100°C. In the sugar house, however, the system consists of sugar, water, acid and neutral salt; the action of the neutral salt decreases (under the ionic hypothesis) the concentration

* Since the above was in type, Mr. Geerligs has suggested that the discrepancy in the results was due to the fact that neutral inorganic salts only invert sucrose in the presence of glucose in the case where they occur in feeble concentration. Highly concentrated salt solutions are without invertive action.

of the hydrogen ions, and it is for this reason that it is possible to work juices with so high an acidity; the greater the amount of neutral salt the higher can be the acidity. A heavily limed juice, with the lime '*cut out*' by excessive sulphuring will contain a large amount of neutral salt, and can be worked with a higher acidity than one not so heavily limed. This point is empirically known to many West Indian sugar boilers.

The Deming Process.—This process which was introduced a number of years ago has undergone numerous modifications from time to time, and at the present time is worked under more than one combination. Included in the scheme are two distinct ideas, the raising of the juice to a temperature of about 230° F. under pressure (*superheat clarification*) and the use of a specially designed form of a continuous settler. The different parts of the apparatus are described below.
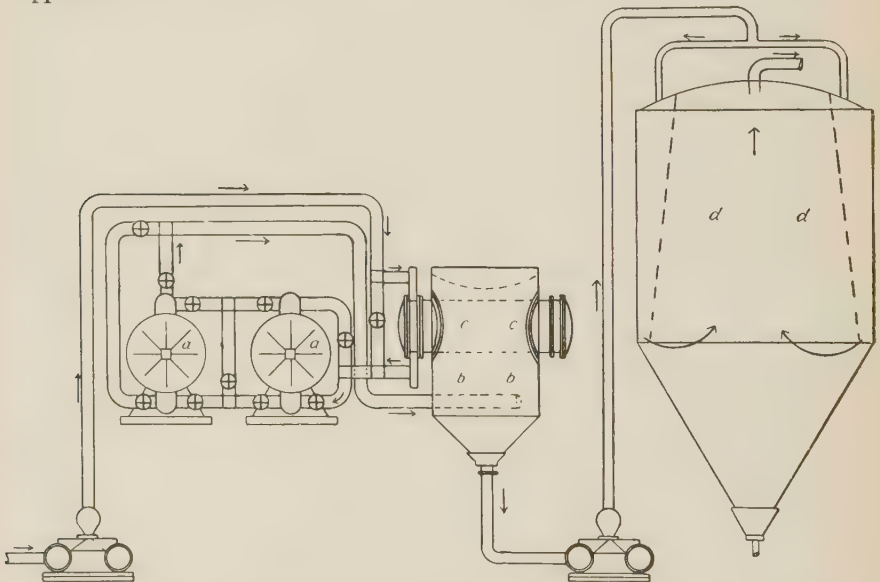
Fig. 147.

The Digester.—The digester, *aa Fig. 147*, is a combination of return current tubular horizontal heaters of conventional pattern; they are worked in pairs or in sets of three; exhaust steam is employed as a heating agent in that heater through which the juice first passes, and live steam in the later ones.

The Absorber.—The absorber is a combined cooler and heater; in the earlier plants this consisted of a tubular element, in the interior of the tubes of which the superheated juices from the digester circulated; on the outside of the tubes cold juice on its way to the digester passed; an interchange of heat occurred, and juice at a temperature of about 200° F. was delivered to the settling tanks. The absorber shown at *bb, Fig. 147*, is the most recent form. It consists of a closed outer vessel wherein is maintained a

vacuum of about six inches; the superheated juice from the digesters is discharged into this vessel; in the upper part of the absorber is a tubular element *cc* within the tubes of which the cold juice circulates; the superheated juices on entering the absorber at once boil under the reduced pressure, and the vapours given off condense on the tubular element, at the same time raising the temperature of the cold juice therein contained.

The Settling Tank.—The continuous settling tank is shown at *dd*; it consists of a cylindrical portion mounted on a funnel-shaped lower part. Inside is arranged a truncated cone of sheet iron. The juice enters through four pipes and follows the course indicated by the arrows, depositing its suspended matter on the sides of the tank, and on the cone; on leaving the tank the juice passes direct to the evaporators. Periodically the deposit of dirt is discharged through the pipe at the bottom of the tank and sent to the presses. The settler shown in *Fig. 147* is closed; in the earlier plants open settlers were used, and these tanks were often arranged in series, the juice from the first tank dividing into two currents, so that the velocity of flow was halved, and an opportunity given for a thorough deposit of the dirt.

The Deming plant is sent out equipped with carefully thought out arrangements for the control of liming and sulphuring and of the temperatures in the various parts of the plant. So as not to cause confusion these arrangements are not shown in the drawing, which is confined to the essential parts of the apparatus.

Mechanically, and from the point of view of steam economy, there is no doubt that this process is very efficient, but from the chemical standpoint it has been subjected to very severe criticism; any slight error in controlling the amount of lime or sulphur gas added will, at the high temperature which forms a part of the process, result in a serious loss of sugar; and in a number of instances where the plant has been installed the superheat part of the scheme has been dropped, the mechanical ideas being retained.

The following figures dealing with the process are due to Beeson[22] :—

Juice.	Total Solids.	Sucrose.	Solids not Sugar.	Purity.	Glucose.
Diffusion	14·9 ..	11·22 ..	1·69 ..	75·3 ..	1·99
Ordinary Clarification	14·9 ..	12·04 ..	0·83 ..	80·9 ..	2·03
Deming Clarification..	14·9 ..	11·58 ..	1·29 ..	77·7 ..	2·03
Diffusion	14·9	11·78 ..	1·11 ..	79·1 ..	2·01
Ordinary Clarification	14·9 ..	11·65 ..	1·21 ..	78·2 ..	2·04
Deming Clarification .	14·9 ..	10·85 ..	2·06 ..	72·8 ..	1·99

Juice.	Glucose ratio.	Total Proteids.	Albumenoids.	Amides.	Alcoholic Precipitate.
Diffusion	17·7 ..	·248 ..	·0617 ..	·1863 ..	·105
Ordinary Clarification.	16·9 ..	·205 ..	·0416 ..	·1634 ..	·202
Deming Clarification..	17·5 ..	·208 ..	·0434 ..	·1646 ..	·171
Diffusion	17·1 ..	·215 ..	·0733 ..	·1417 ..	·246
Ordinary Clarification.	17·5 ..	·201 ..	·0538 ..	·1472 ..	·336
Deming Clarification..	18·3 ..	·202 ..	·0447 ..	·1574 ..	·297

Edson[23] experimenting at Calument, Louisiana, found juices treated by the Deming process to filter more rapidly than others.

	Temperature of Clarification.			
	215° F.	230° F.	248° F.	260° F.
Filtration started at ..	3·45 ..	3·45 ..	3·45 ..	3·45
Juice freed from mud at	4·15 ..	4·05 ..	3·56 ..	3·56
Time of filtration	30 min...	20 min...	11 min...	11 min.
Using juice heated to 260° F. as a unit, the time of filtration was	2·75 ..	1·82 ..	1·00 ..	1·00

The process was also subjected to a trial by Geerligs[24], in Java, the factory in question working alternately the Deming and the older process. The analyses of the juice show no difference, but the analyses of the molasses indicate that more gums were precipitated by the Deming process.

				Ash.	Lime.	Gum.	Silica.
Molasses,	Cheribon cane,	Defecation	4·67 ..	0·207 ..	0·808 ..	1·28
,,	,,	,,	Deming ..	4·59 ..	0·245 ..	0·720 ..	1·09
,,	Muntok	,,	Defecation	4·50 ..	0·370 ..	0·636 ..	1·32
,,	,,	,,	Deming ..	4·55 ..	0·331 ..	0·604 ..	1·24

Geerligs remarks that "from a chemical point of view Deming's superheat clarification stands in no respect behind the usual defecation process, whilst its mechanical advantages are many."

Increase in Purity.—The increase in purity due to the action of lime varies with the nature of the bodies in the juice; thus with unripe cane much of the nitrogen is present as amide and is not precipitated, whereas in mature cane the nitrogen appears chiefly as albumenoids and is precipitated. Similarly a greater or less quantity of phosphates in the juice will affect the increase in purity; the figures from the *Mutual Control of Java Factories* show an increase of from 1·5 to 1·9 units where the purity is about 85; a similar increase is usual with the purer juices of the Hawaiian Islands and the figures given by Browne[25] as typical of Louisiana indicate a similar increase. In addition to the increase in purity due to the action of lime and heat, a further increase follows due to the precipitation of bodies as scale on evaporation; this increase may amount to as much as a unit between the clarified juice and the syrup.

Abnormal Purities.—Geerligs[26] in particular has described instances of juices showing a very high purity which fell to normal figures in the syrup; he failed to obtain indications of any bodies precipitable by lime to which the phenomenon could be ascribed and was inclined to think it due to presence of alcohol formed in fungus-attacked canes. Pellet[27], however, thinks imprisoned air a more likely cause; either of these bodies would give a fictitiously low degree of Brix and would disappear in the evaporation.

THE CLARIFICATION OR DEFECATION OF THE JUICE.

REFERENCES IN CHAPTER XIII.

1. *Ency. Brit.* X. Edit. Art. *Sugar.*
2. *I. S. J.*, 88.
3. After Spencer's *Handbook for Beet Sugar Manufacturers.*
4. *Arch.*, 1896, 224.
5. *Bull. Assoc.*, *15*, 163.
6. *Louisiana Bulletin*, *2*, 38, 1407.
7. English Patents, 11790 and 19815 of 1896 and 25642 of 1898.
8. German Patent, 174097 of 1905 ; English Patent, 8232 of 1907.
9. *I. S. J.*, 107 and 108.
10. English Patent, 15274 of 1903.
11. *Bull. Assoc.*, *20*, 131.
12. *Deut. Zuck. Ind.*, 1909, 9.
13. *Jour. Prak. Chem.*, 30, 95.
14. *Ber. Deut. Chem. Gesel.*, 16, 765 ; 17, 2175.
15. *Zeit. Phys. Chem.*, 4, 226.
16. *Bull.* 35, *Agric. H.S.P.A.*
17. *S. C.*, 313.
18. *Jour. Am. Chem. Soc.*, 18, 693.
19. *Jour. Chem. Soc.*, 57, 834.
20. *Jour. Am. Chem. Soc.*, 30, 1564.
21. *Bull.* 9, *Path. H.S.P.A.*
22. *S. C.*, 330.
23. *S. C.*, 345.
24. *I. S. J.*, 19.
25. *I. S. J.*, 91.
26. *I. S. J.*, 111.
27. *I. S. J.*, 119.

CHAPTER XIV.

THE CARBONATION* PROCESS.

The carbonation process, which is quite generally adopted in beet sugar factories, has only been applied to the manufacture of cane sugar in a few instances in Java and India. This process, though very successful in beet factories, gave bad results when first introduced into cane sugar factories owing to the presence of glucose in cane juice,—this body not being a constituent of sound beets. It is owing to the efforts of Geerligs and Winter in Java that the process has been made even practicable, but that it will ever be generally adopted is problematical.

The essential principle of the process is the use of a large quantity of lime in the clarification, giving a very copious precipitate of organic non-sugar, the excess of lime being removed by the passage of carbon dioxide as an insoluble carbonate. Besides precipitating organic matter, the lime acts on the glucose, converting it into saccharic, glucinic, and lactic acids, the proportions of each being dependent on the temperature at which reaction takes place.

Single Carbonation.—In the single process a quantity of lime which, calculated as dry anhydrous lime, amounts to as much as 1 to 1·5 per cent. of the weight of the cane is added to the juice; carbon dioxide generated by the combustion of limestone in limekilns is pumped through the juice until the latter is neutral; the juice is all this time at a temperature not exceeding 55° C.; the temperature is now raised to 90° C., and the juice filtered; in some cases the juice is filtered *en masse*, and in others it is allowed to settle and only the scums filtered.

Double Carbonation.—In the double carbonation process the juice is limed as above at a temperature not exceeding 55° C., and carbon dioxide passed in until the alkalinity is one represented by ·05 per cent. lime; the juice is then separated from the precipitate by means of filtration, raised to the boiling point, saturated with carbon dioxide, boiled for a few minutes to break up bicarbonates, and again filtered.

The point at which the passage of carbonic acid gas is stopped is indicated by a clear, bright coloured juice with a rapidly settling precipitate.

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* I write '*carbonation*' in preference to '*carbonatation*,' as being etymologically the correct form, although the latter spelling is adopted by Geerligs and by Ware.—(*N. D.*)

Chemistry of the Process.—The chemistry of the process is thus explained by Geerligs[1]. At temperatures near the boiling point the action of lime on glucose is to form chiefly saccharic and glucinic acids : if the temperature, however, does not rise above 60° C., saccharic and lactic acids are chiefly formed, and only small quantities of glucinic acid. The glucinic acid formed combines with the lime to produce an insoluble basic glucinate ; this basic glucinate is insoluble in an alkaline medium at temperatures below 60° C., but redissolves with rise of temperature or on neutralization of the free alkali. In the single process, then, the glucinate of lime, after being insoluble, again becomes soluble, and re-enters into solution ; in the double process it is removed.

In addition to the action of an excess of lime on glucose, gummy and other matters are only precipitated by an excess of lime and considerably more impurities are thrown down by the excess of lime than in the ordinary process ; on neutralization these bodies redissolve, and the final effect is the same as if lime had only been added in the usual quantities. This effect takes place in the single process, and it is only by filtering the strongly alkaline solution, and by removing the lime afterwards that the full benefit of the carbonation process is obtained.

Below are given details of analyses (by Geerligs) of juices treated by the carbonation process ; analyses of the scums are given in the succeeding chapter.

	Brix.	Sugar, Per cent.	Glucose, Per cent.	Purity.	Glucose ratio.	Pectine, Per cent.
Mill juice	18.4	15·72	0·92	85·6	5·9	0·634
Clarified by defecation	18·6	15·99	0·95	86·1	5·9	0·292
Clarified by carbonation	16·9	14·65	0·44	86·7	3·0	0·142

Use of Carbonation Process.—The double carbonation process is used in a few factories in Java, and perhaps in one or two elsewhere. By its use a white sugar intended for direct consumption is obtained with less trouble than can be obtained by any other process ; in this regard, however, the writer would remark that the best white sugars of Mauritius made by a defecation process combined with the use of sulphur and phosphoric acid are equal to any that he has seen prepared by the carbonation process.

The single carbonation process appears to be adapted to factories which obtain a gummy juice, and is not adapted for making white sugars.

Effect on Manufacture.—The decomposition of the glucose by lime gives rise to organic acids and hence carbonated juices contain more salts than do defecated juices. In discussing this point, Geerligs[2] in 1895 seems to imply that carbonation molasses contain more sucrose per unit of water than do defecation molasses; this distinction he correlates with his Theory of Molasses (cf. *Chap. XIX.*) ; on the other hand he points out that owing to

the decreased quantity of non-sugar the actual loss of sugar is not increased; in addition carbonation molasses are less viscous and lighter coloured, so that they are more easily removed in the centrifugals.

Later analyses of carbonation molasses published by Geerligs in " *Cane Sugar and its Manufacture*" do not show a higher purity than do defecation molasses; the average of eight carbonation factories and of sixty-seven defecation factories are as under:—

	Brix.	Total Solids Per cent.	Polari- zation.	Sucrose Per cent.	Apparent Purity.	True Purity.	Glucose.	Gums.	Lime
Carb...	83·7	78·6	31·1	31·3	37·1	39·8	21·6	·74	1·38
Def. ..	85·4	80·0	28·8	33·9	33·7	42·4	23·6	1·95	·53

It will be observed however that the difference between the polarization and sucrose per cent. is much less in the carbonation molasses, than in the defecation molasses; this is of course to be correlated with Lobry-de-Bruyn's and Van Ekenstein's observations on the transformations of reducing sugars in the presence of alkalies.

Finally, Hazewinkel[3] in obtaining a formula for available sugar allows a loss of 5 per cent. of sucrose in the carbonation process; this would seem to imply that the recovery of sucrose in this process is less than in the defecation process, and is to be ascribed to the action of the lime in large quantity on the sucrose.

Details of Routine.—It remains to describe the practice of the process, which may be varied in details to suit the requirements of different factories or the ideas of different manufacturers. In the single process, the juice is received as usual in tanks, where it is treated with from 10 per cent. to 20 per cent. of milk of lime, standing at 20° Brix. Attempts made to introduce the lime in a dry state have not been successful, but to prevent the considerable dilution that would be necessary if the lime were mixed with water, the dilute washings from the filter presses have been substituted. But it has been found that a badly filtering juice thereby results. The carbonation may be performed in the vessels in which the juice is received, or the limed juice may be run off into special tanks; the exact amount of lime added not being a matter of importance, the use of liming tanks is not essential.

In the double process, the first carbonation is performed in the vessels in which the lime is added, after which the juice is filtered *en masse* or else decanted and the scums only filtered. The cleared first carbonation juice is then passed on to the saturation or second carbonation tanks where the process is finished as already indicated.

It is general to keep the scums from the two carbonations entirely separate, but in some beet sugar factories it is the custom to mix and filter them together, a more easily treated material being thus obtained. This is a

process not recommended by the best authorities, the interaction of the two scums tending to reintroduce into the juice bodies which it is desired to eliminate.

In the carbonation process the quantity of lime used is very considerable and it is essential that labour-saving devices be used in connection with it. A factory of moderate size working up 5000 gallons of juice per hour will use about 500 gallons of milk of lime, equivalent to about 500 lbs. of dry lime. The milk of lime may be mixed on the basement and elevated to the clarifier loft by a pump or montjus, or the dry lime may itself be elevated by means of a hoist. In either case power is required to drive the lime mixing apparatus.
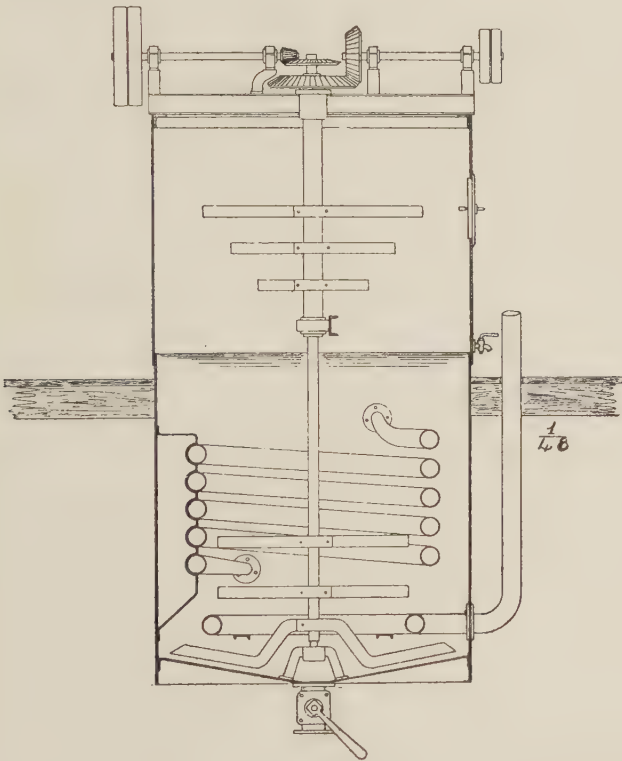
Fig. 148.

This consists of a rectangular or cylindrical tank of suitable capacity, in which is placed centrally a vertical shaft, fitted with a series of horizontal blades. On the top of this shaft is fixed a horizontal bevel wheel gearing with a vertical one which receives its motion by belt gearing from any convenient shafting, the power required not being sufficient to demand a separate engine ; the liming tanks have similar appliances to ensure a complete mixture of lime and juice.

Carbonating Tanks.—The carbonating or saturation tanks, *Fig. 148*, are made either rectangular or circular; the latter form is preferable as tending to a more uniform distribution of the carbon dioxide. They are often provided with an iron lid, to which is fitted a short chimney. Where this device is not utilized, the froth is broken up by means of a jet of steam brought to play upon the surface. A mechanical arrangement, consisting of a scraper passing over the surface of the juice, is sometimes used, and a stirring device, as shown in *Fig. 148*, is also employed.

The height of the liquid undergoing treatment varies in practice from 4 to 9 ft., and owing to the frothing the vessels are not filled to within 1 or 2
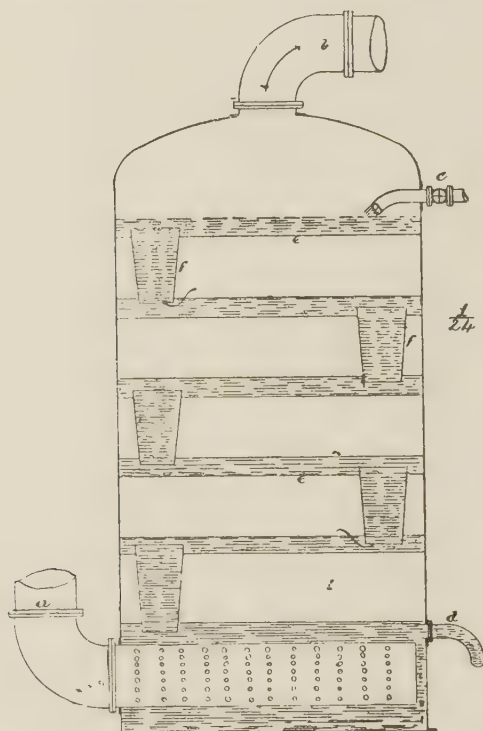
FIG. 149.

ft. of the top of the containing vessel. No useful purpose is served by decreasing the height of liquid, as if too low there is danger of carbon dioxide passing away unutilized.

To distribute the gas uniformly through the liquid various devices are used. The commonest method is to use a perforated coil, for which may be substituted a perforated disc or drum: any method which secures uniform distribution of gas is effective. In addition to the gas distributing coil, steam coils are provided for boiling the juice; an allowance of 1 square foot heating surface for every two gallons capacity is sufficient.

Gas Washer.—The carbon dioxide used in this process is, of course, generated on the spot by burning limestone; after being generated in the kiln, the gas is passed through a gas washer, a form of which is shown in *Fig. 149;* it consists of an upright cylindrical vessel in which is placed a series of transverse horizontal partitions e; in each of these, and projecting a few inches, are fitted the funnels f; water is pumped into the vessel by the pipe c and flows over the partitions, down through the funnels and out through the pipe d. The gas from the kiln enters by the pipe a, the lower end of which is perforated, and flows upwards in the direction indicated by the arrows. In the passage of the gas the dust carried over is deposited and the gas cooled down to a temperature of 40° C. Various other forms of gas washers are made; in one, perforated plates take the place of the transverse partitions described above. Any of the forms of jet condensers described in connection with evaporation serve equally well as gas washers.

In certain beet factories the gas evolved from the kiln is purified by being passed through closely-packed carbonate of soda or through a solution of this substance; the object of this procedure is to eliminate any sulphurous acid which may be present, as the coke employed contains sulphur.

Lime Kilns.—The carbon dioxide requisite for the carbonation process is obtained by burning lime in kilns at the factory, which in this case makes its own temper lime from crude limestone. Lime kilns are of two types, *continuous* and *intermittent*, and the former of course is the type required for a sugar factory. They may also be classed as *long flame* and *short flame* kilns. In the former the fuel is burnt on a hearth, and the products of combustion pass through the limestone in the kiln proper. In the latter the fuel and limestone are mixed together and charged into the kiln from the top. It is very general to use a combination of short and long flame burning. The latter is more expensive as regards fuel, but gives a purer product, as in short flame burning the lime is contaminated with the ash of the fuel. When using good quality coke, with short flame burning, 2 per cent. of the product consists of the ash of the fuel. When wood is used a rather larger percentage is present.

In *Fig. 150* is shown a section of a continuous type of kiln very generally used in beet factories, which can be employed as a long or short flame kiln, or as a combination of both methods. The kiln consists of a tapering masonry shaft of forty to fifty feet high; the diameter at the base is fifteen feet, and at the beginning of the curved portion twelve feet. Many kilns are built with much narrower shafts—a diameter of eight feet for a height of fifty feet not being uncommon. The interior of the kiln is lined with fire-brick, d; the exterior being of common brick, e; the whole is sometimes cased with iron plates to prevent leakage of air through the masonry, and sometimes a layer of non-conducting material is placed between the fire-brick and outer casing.

The base of the kiln is conical so as to allow the lime to gravitate towards the doors, *b*, of which there are eight provided for the removal of the burnt lime. The limestone, or mixture of limestone and fuel, is introduced into the kiln at the top, which is kept closed by the cone, *k*. A charge being dumped on to the cone from the waggon, *h*, the cone is lowered by moving the lever, *m*. and distributes the charge evenly in the kiln. At *f* tubes are let into the wall to allow of the process being watched. These tubes are provided with shutters so as to regulate the supply of air. At *a* are the hearths on which the fuel is burned, the products of combustion passing by way of *c* up through the kiln; three or four hearths are usually provided. The products of combustion pass by tubes to the chamber *l*, whence they are aspirated by a pump to the gas
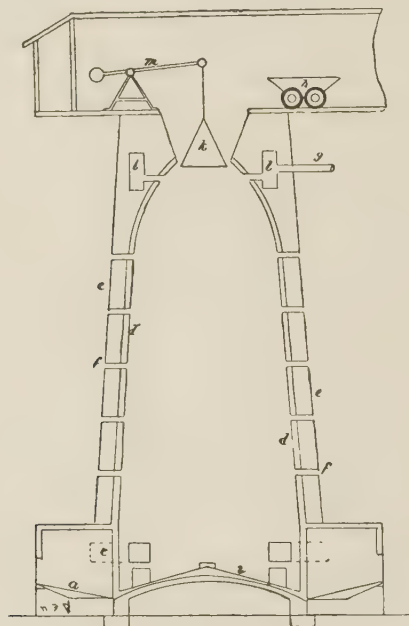
Fig. 150.

washer, and eventually to the carbonating tanks. The lime and fuel (where the two are mixed) are raised to the platform at the top of the kiln by a pulley hoist, and in very large installations by a hydraulic lift.

A very complete study of the lime kiln has been made by Gallois, from whose researches the following notes are taken. The investigation, of course, refers to beet sugar manufacture, but as the amount of lime used is the same per ton of cane or beet, his results are applicable to the cane sugar industry. Gallois' figures are expressed in the metric system, and these have been converted by the writer to English units.

A lime kiln for short flame burning without hearths should have a capacity of 14 cubic feet per ton of cane per 24 hours. For the decomposition

of 100 lbs. limestone of 95 per cent. purity, a theoretical minimum of 6 lbs. coke is required; this corresponds to one volume coke to six volumes of limestone. In practice, from four to five volumes of limestone are used with one volume of coke, and some authorities allow three volumes.

Coke gives twice the calorific value of average wood, and accordingly 12 lbs. wood to 100 lbs. limestone would be required.

The following are the points to be observed to obtain a good result in the kiln :—

1. The limestone should contain a minimum of silica and alumina.

2. Washed coke, containing not more than 7 per cent. of ash, should be used.

3. The proportion of coke and limestone should be carefully regulated.

4. The charges should be frequent and regular.

5. The lime should be drawn successively from the doors in turn.

6. Only two-thirds of the volume of the kiln should be occupied.

7. The aspirating pump should work slowly and regularly.

8. Air should not be allowed to suck back through the gas pipe.

The objectionable constituents which occur in limestone are silica, alumina, magnesia, and sulphate of lime. If either of the two former are present during the calcination, fusible silicates and aluminates of lime and magnesia are formed, giving rise to what is known as *scaffolding* in the kiln—*i.e.*, a fused mass is formed, preventing the descent of the lime. In addition, their presence prevents the lime slaking properly; furthermore, silica introduced into the juice may dissolve in the presence of alkalies and be precipitated as scale in the evaporators, besides causing difficulties in the filtration. Magnesia and sulphate of lime also cause scale in the evaporators.

Below are given analyses by MM. Gallois and Dupont of different types of limestone :—

Material.	Bad.	Passable.	Excellent.
Moisture	4·10	6·25	1·21
Sand, clay, and insoluble matter	4·50	3·17	0·55
Organic matter	1·20	1·12	0·41
Soluble silica	2·10	0·64	0·20
Oxides of iron and alumina	0·37	0·15	0·23
Calcium carbonate (limestone)	85·86	87·93	96·58
Magnesium carbonate	0·95	0·53	0·50
Soda and potash	0·05	—	—
Undetermined	0·87	0·24	0·32

The inefficient working of a kiln may arise from the following points :—

1. Scaffolding, which may as already mentioned be caused by the presence of silica or alumina, and also by careless work in changing or in mixing the limestone and fuel.

2. Withdrawal of unburnt lime when too little fuel is used or when combustion is too rapid.

3. Presence of carbon monoxide, due to too little air being admitted for complete combustion, or to a too low temperature in the kiln.

4. Presence of air due to leaks in the masonry or to air sucking back, or to working the pump too fast.

The composition of the gas from the kilns varies within wide limits, the theoretical maximum of carbon dioxide being 38·7 per cent.; in general practice the percentage lies between 25 per cent. and 30 per cent., with from 1 per cent. to 3 per cent. of oxygen and 65 per cent. to 70 per cent. of nitrogen. Traces of carbon monoxide may be present but should not rise above 1 per cent.; sulphur dioxide derived from sulphur in the coal may also occur.

Carbonic Acid Gas Pumps.—The pumps used to aspirate the carbon dioxide are now slide valve pumps similar in design and construction to those used in the dry vacuum process described in the Chapter on Evaporation. A table of their capacities is given below, taken from a Continental maker's catalogue.

Quantity of gas sucked per hour, cb.m..	50	825	1050	1300	1800	2050	3375	4050
Diameter of steam cylinder, mm.	275	350	375	400	470	500	600	700
Diameter of carbonic acid cylinder, mm.	500	550	600	650	750	800	1000	1100
Piston stroke, mm..	470	550	550	630	700	700	800	1000
Revolutions per minute	75	70	70	65	60	60	55	45
Steam inlet, mm. ..	60	80	80	90	110	110	140	170
Steam outlet, mm..	70	90	90	100	120	120	150	185
Diameter of suction pipe, mm.	110	125	135	150	175	190	240	270
Diameter of delivery pipe, mm. ..	100	110	125	140	160	170	220	250

Review of Process.—The essential question with regard to any new process is whether a return is given on invested capital. An estimate of necessary working expenses for a factory working 1000 tons of cane per day over a crop of 100 days is given below.

The necessary extra plant over and above that needful for the ordinary defecation process will include a limekiln, gas washer, and carbonic acid gas pump; and the carbonating tanks simply replace the clarifiers and eliminators used in the defecation process.

The cost of these may be estimated as: limekiln, £3500; gas washer, £150; carbonic acid pump, £600; a total cost of £4250.

The extra current expenses for a crop of 100,000 tons will include purchase of limestone sufficient to give 1500 tons of lime, for which would be required 2678 tons pure limestone, or, say, 2900 tons actual crude material. In certain instances, such as in Mauritius, estates near the seaboard could lay the coral reefs under contribution, and obtain limestone at the factory at a cost of 2s. to 3s. per ton. Then the lowest cost of the limestone would be £435, but in other cases, such as in Demerara, the cost of transporting limestone would be prohibitive.

In general, in beet sugar factories eight pounds of coke are required per hundred pounds of limestone; wood in tropical countries is as a rule cheaper than coke, and, taking the relative calorific value of wood to coke as 1 : 3, twenty-four pounds of wood will be required per hundred pounds of limestone, thus for the 2900 tons of limestone 696 tons of wood; in very favourably situated estates wood can be obtained at the factory at a cost of 6s. per ton, giving the cost of fuel as £208 16s.

The extra labour in working the kiln may be put at five men per shift, and for the hundred days' campaign will cost £60.

The large quantity of water used with the milk of lime requires additional expense in evaporation; if the 1500 tons lime be employed at a density of 20° Brix approximately 6000 tons of water are also added. Allowing at the triple effect one pound of coal to evaporate twenty pounds water, 300 tons of coal will be required, which, at 25s. per ton (a price frequently reached in the tropics), will cost £375.

The total extra cost, then, allowing 10 per cent. interest and depreciation on invested capital, will be for the 100,000 tons of cane £1508 16s., or 3·621 pence per ton of cane, and allowing a 10 per cent. recovery on the canes, 3s. per ton of sugar; and this is an estimate made for circumstances more favourable than would generally be the case.

To counterbalance this extra cost the value of the crop must be increased, and an increase can only be looked for on the score of quality, as the figures published by the West Java Experiment Station show conclusively that no greater extraction is obtained by this process.

In making high-class white sugars for direct consumption, an expenditure of 1s. 6d. to 1s. 9d. for chemicals (including lime) per ton of sugar is usual. The difference between this amount and that estimated as the expense of the carbonation is really very small compared with the profits on a ton of sugar expected to be realized on a large, well-managed estate. Very slight differences would turn the scale very decidedly in favour of one or other of the processes.

What is, however, claimed as an advantage for the process is, in certain cases, one of its greatest drawbacks, and that is the destruction of the glucose. In countries such as Java and Mauritius, where either from excise reasons or want of a market rum or arrack cannot be made, loss of glucose is of no consequence, but in districts such as Demerara where the rum forms a very important by-product, any destruction of glucose is a direct and serious loss, which would at once put the process on an uneconomical basis. Where, however, rum is not made, and fuel and limestone can be cheaply obtained and a gummy impure juice is to be treated, the process might meet with financial success.

REFERENCES IN CHAPTER XIV.

1. *S. C.*, 334.

2. *S. C.*, 313.

3. *Arch.*, 1905, 197.

CHAPTER XV.

THE FILTRATION OF THE JUICE.

In a previous chapter, it was shown how the juice was separated into a partially clear liquid and into a dirty liquor, formed out of the settlings and the floating scum removed from the surface of the juice in the clarifiers;
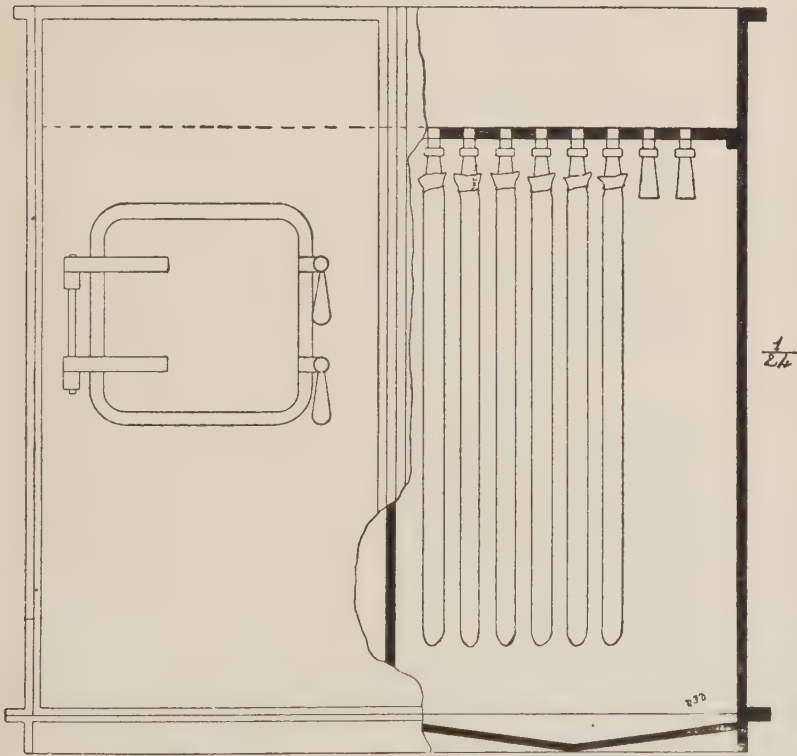
FIG. 151.

roughly about 90 per cent. of the juice will be obtained in the clear liquor and 10 per cent. in the scums, the latter containing about 10 per cent. of suspended solid matter. The scums are received in tanks where they are limed and allowed to settle, the clear supernatant liquor being decanted and added to the main bulk of the juice; the scums are then passed through the filter presses, the clear filtered liquor being passed on to the evaporators.

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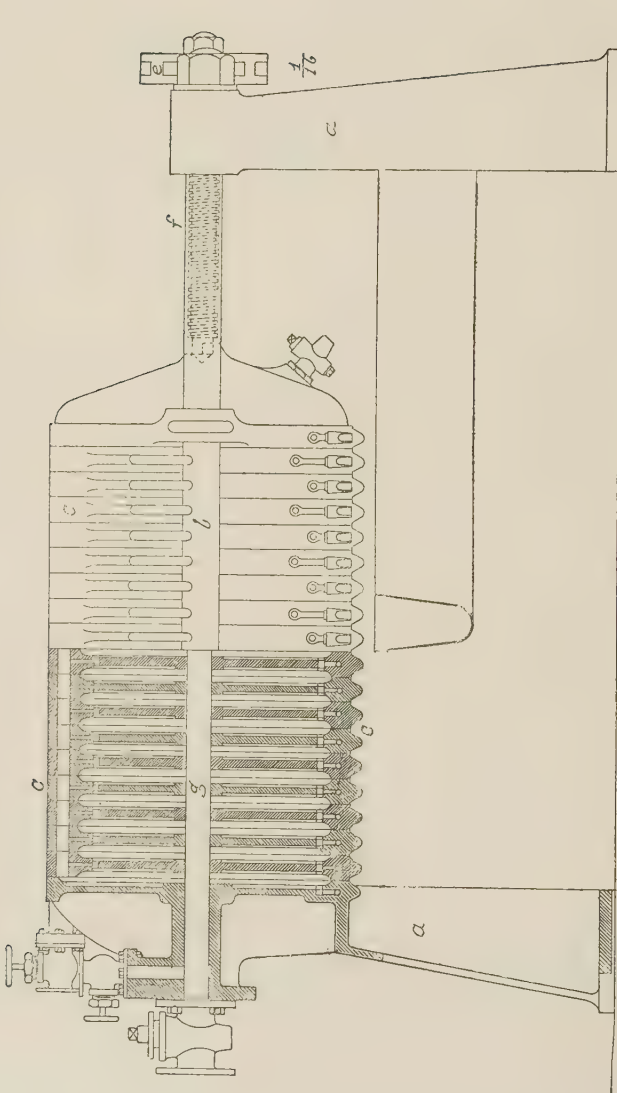
Fig. 152.

In some factories the partially clarified liquor is also filtered *en masse* in filters known as '*mechanical filters*'; in others the juice is cleaned by boiling, and by skimming off the floating impurities; the vessels in which this process is carried on are known as 'eliminators' and in Java as 'Fletcher pans.'

Taylor Bag Filters.—The Taylor bag filter consists of stockings of stout cloth, generally about six feet long and four inches in diameter; these stockings are suspended in groups of from twenty to fifty in a horizontal frame; the frame is perforated with holes in rows a short distance apart; into the holes are fitted gun metal sockets furnished with screw threads for the reception of the gun metal cones to which the bags are tied. The whole system of frame and bags is enclosed in an upright iron box, access to which is afforded by means of close-fitting doors; the sides of this box project a height of about two feet above the frame; the scums being allowed to flow over the frame, the clear juice passes through, the dirt being retained in the stockings. A steam connection is usually fitted up in the interior of the box so that the high temperature necessary to rapid filtration may be maintained. A view partly in section and partly in elevation is shown in *Fig. 151*.

Frame Filter Press.—In *Fig. 152* is shown a view partly in section and partly in elevation of a central feed frame filter press; it consists of a heavy cast-iron frame *b*, on which are supported a number of plates *c*; on the sides of the plates are cast lugs from which the plates depend. The latter are made either square or circular, generally the former. On their surface are formed a number of corrugations about one quarter of an inch deep; in the centre of each is an opening so that when all the plates are fixed in position there is a circular conduit running through the press. Near a lower angle of each plate is an aperture which communicates by a channel with a cock placed at the bottom of one of the sides of the plate, and through which the filtered juice is drawn off. Filtration is made through strong twill cloth as a general rule, but in the absence of other material ordinary gunny bags form an efficient substitute. Cloths, with circular holes cut to correspond with the holes in the plates, are hung over each plate. The edge of the cloth is secured in the hole in the plate by means of a hollow screw with a deep rim. In working the press after all the cloths have been placed in position, the whole is screwed tight by means of levers acting on the wheel *e*, which works the screw thread *f*, and by means of suitable piping juice is pumped or forced by a montjus through the press along the conduit *g*; the clean juice passes through the cloth and the suspended dirt is caught between the cloths. At the upper corners of the plates are openings communicating with another set of piping by means of which water or steam may be forced through the scum after the press is filled. This type of press is not very convenient; the bags have a great tendency to tear away at the centre, and washing to remove

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sugar in the cake is not, as a rule, effective. A rather different system is now usually followed. In *Fig. 153* are shown, in section, the types of plate used. One plate is solid, and the other consists of a frame only, *a*. The solid and hollow plates are placed in the press alternately. At the angles of both frame and press are the circular openings *b* and *c*, so that in this press there are two conduits, that at *b* is for the passage of the juice, and that at *c* for the washing water. The channel *h*, in the hollow plates, conducts juice to the interior of the press, and in the solid plates there is a similar channel *i*. A light joint is made along the conduits by placing indiarubber rings, *d*, in the closed openings *b* or *c*, as the case may be. At *g* in the solid plate is an opening communicating with the cock *f*. Bags without openings are hung over the solid plates, but do not cover the conduits *b* or *c*. Scums being forced into the press by the conduit *b*, pass through the channels *h* and fill the spaces between the two solid plates formed by the hollow plates. The clear juice passes out through
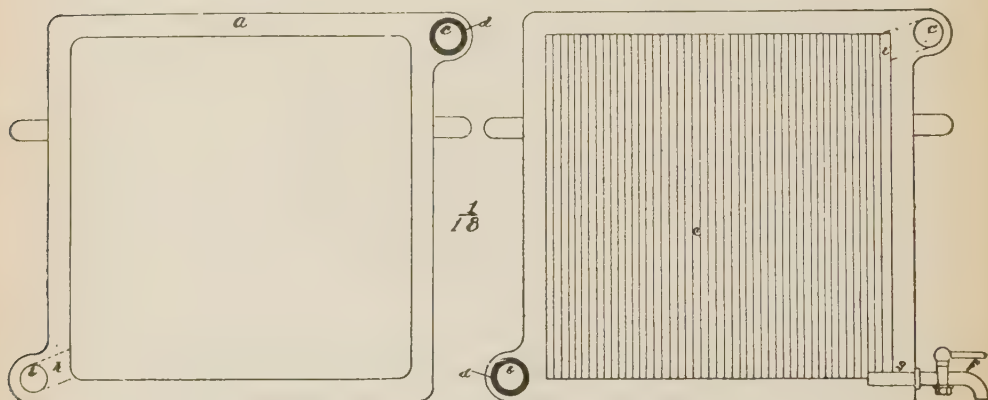
FIG. 153.

g, the scums being caught between the bags. To wash the cake, water is forced through the conduit *c*, and passes through the cake in a direction opposite to that by which the juice travelled. The advantage of this type of press over the central feed press is that the washing is more effectively performed, and that the bags not needing to be cut have a longer life.

Capacity of Filter Presses.—To filter scums an allowance of two square feet of filtering area for every gallon per hour is necessary, and taking the scums as 10 per cent. of the volume of the juice, two square feet of filtering area should be allowed for every 10 gallons of juice per hour; this is a minimum allowance and should be increased at least 25 per cent. to allow for time lost in changing cloths, &c. Where, as now is often the case, the scums are thoroughly washed, or are re-pressed, a greatly increased capacity is called for.

Loss of Sugar in Presses.—The loss of sugar in the presses depends on the purity of the juice, as influencing the amount of cake formed, and the degree to which the washing is carried. With the Taylor filters a cake containing from 65 per cent. to 70 per cent. of water, and which cannot be easily washed, is obtained; a loss of 2 per cent. of the sugar in the juice can easily occur here. With frame filter presses a cake containing from 50 to 55 per cent. of water and weighing from 1 to 1·5 per cent. of the juice is obtained, and this cake without washing will contain from ·8 to 1 per cent. of the sugar in the juice. This loss can be almost entirely recovered by washing; the limit to which this washing can be carried depends on the evaporative capacity of the factory, and on the filtering area available. In the Hawaiian Islands many factories wash the cake until it contains no more than 1 per cent. of sugar; the loss in this case is very small and less than ·1 per cent. of the sugar in the juice. It should be noticed that it is only in large factories that so complete an exhaustion can be obtained. In a factory turning out annually 50,000 tons of sugar, a loss of 1 per cent. of the sugar entering with the juice indicates a loss of 500 tons of sugar, and it will be economical to erect plant capable of dealing with this loss; in a smaller factory making only 5000 tons of sugar, the erection of plant to recover the 50 tons of sugar might be uneconomical, as the larger loss would be recovered at a much lower pro rata cost.

The very dilute last washings are often employed at the mill as a macerating agent; it should be remembered however that, as these washings are alkaline, there is a tendency towards dissolving out gummy bodies from the megass. In beet factories these washings are used in mixing the milk of lime, of which much larger quantities are used than in cane factories.

Double Pressing.—In some factories the cake is not washed directly in the presses, but is discharged without washing, and remixed with a quantity of water; the mud is then passed a second time through the presses.

Difficulties in Filtration.—In certain cases, a mud, from which it is impossible to obtain a firm cake, results and such a cake is incapable of washing; the cause of this is probably to be found in the presence of gums or of pectinous bodies in the juice, and is more likely to occur when unripe canes are being milled; in such a case, a better cake may sometimes be obtained by forming in the scums a granular precipitate of oxalate of lime; about 1 per cent. of a saturated solution of oxalic acid is added to the scums, followed by enough lime to restore the alkaline reaction.

Filter Press Pumps.—In many instances the scums are forced through the presses by means of montjus; a montjus (*Fig. 154*), consists of a cylindrical vessel *a a*; it is filled by the funnel *b*; the cock *c* communicates

with the main steam pipe; when the vessel is filled and the cock on the funnel *b* is closed, the cock *c* is opened and the pressure of the steam forces the scums through the pipe *d*, communicating with the press; the emptying of the montjus is indicated by the escape of steam through the pipe *e*. Montjus are usually worked in pairs so that their action is nearly continuous. Instead of montjus, pumps are preferable; those in common use are duplex pumps, which by a simple arrangement are automatic, stopping when the
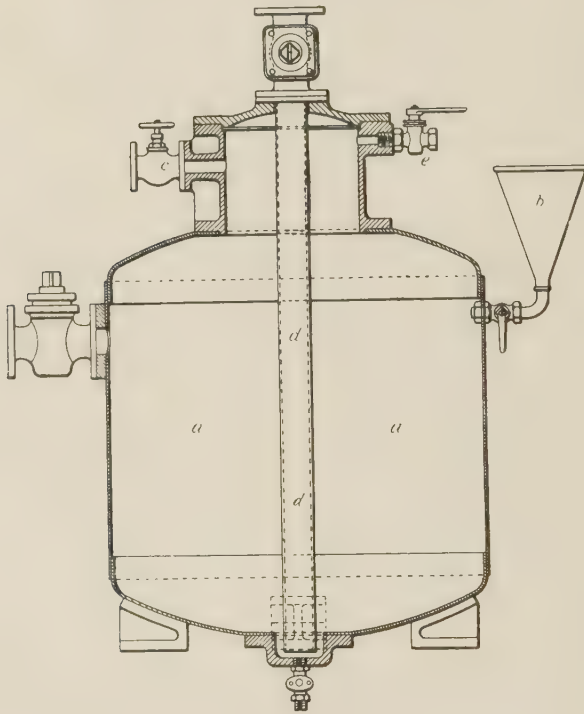
Fig. 154.

pressure in the press which they are filling reaches a certain limit; a small pipe coming from the air vessel of the pump communicates whatever pressure there is in the air vessel to an arrangement which controls the steam valve; when the pressure reaches a limit which can be regulated, the steam valve is closed, and the pump stops working. When communication with the filled press is cut off, and the pump connected on to the next press to be filled the pressure is relieved, and the pump automatically starts working. Several patented forms involving the control of the steam valve by the pressure in the air chamber are on the market; those the writer has encountered have been of German make and are sometimes referred to as 'German pumps.'

Mechanical Filtration.—Filtration of the juice after separation from the scums is practically universal in beet sugar factories and should always be made in cane sugar factories where high-class sugars are being made ; the filtration is made in what are termed *mechanical filters*, a large number of different designs, differing only in detail, being in existence.

In *Fig. 155* are shown sections at right angles to each other of a common type. The filter consists of an iron box provided with a false lid in which are fixed frames *a*. These frames consist of a lattice work skeleton over which is stretched a woven fabric, each frame is complete in itself and is called an element. A separate outlet is provided for each element so that any faulty one can be shut off. All the elements discharge into one common gutter. The juice enters the box at *d*, fills the box below the level of the
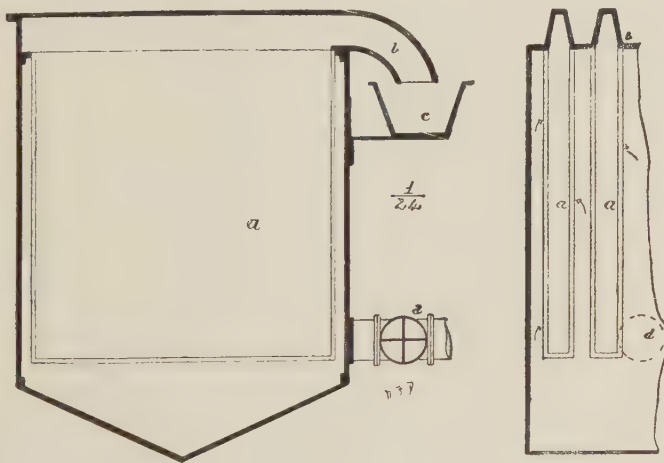
Fig. 155.

false lid and passing from the outside to the inside of the elements discharges at *b*. In the form shown the elements are rectangular, while in some other designs they consist of cylinders, but the principle is the same in all. These filters are generally made with elements of one square metre filtering area, counting, of course, both sides, and in a chamber there will usually be about twenty to thirty elements. The filters will pass on an average 10 gallons of juice per square foot per hour, but as much time is lost in changing cloths, they should not be calculated to pass more than seven gallons per foot per hour. They are also sometimes used to filter syrup on its way to the pans from the triple. When used for this purpose, their capacity is only one-third or one-fourth of what it is for juice. They are usually worked under a head of 6 or 7 ft.

Sand Filtration.—In *Fig. 156* is shown the general type of apparatus used for sand filtration; it consists of a cylinder *a a* about 6 ft. high, and 2 ft. in diameter; within the cylinder is arranged a perforated pipe *b b* about 8 in. in diameter; between the pipe and the outer casing are a number of conical rings, each about 3 in. high, and standing one on top of the other; the space between the central pipe and these rings is filled with sand; the juice or other material to be filtered enters by the pipe *c c*, fills the cylinder, passes through the sand into the perforated pipe and is discharged through the pipe *d d*; the sand when foul is discharged through a manhole at the bottom of the cylinder and is easily washed in a stream of water. The
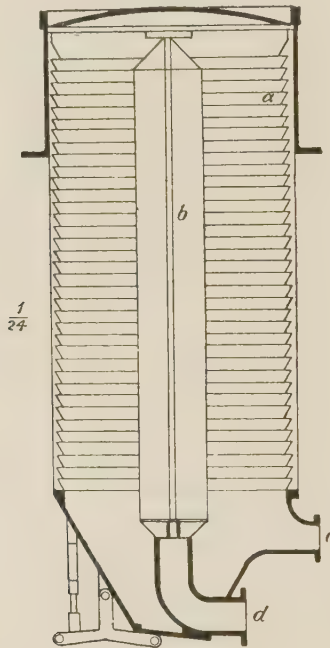
Fig. 156.

perforations in the pipe are of such a size that the sand does not pass through. The capacity of these filters varies with the nature of the juice and with the size of the grains of sand used; as a general rule two filters of the size quoted above should be sufficient for every 1000 gallons of juice per hour.

The advantages of mechanical or of sand filtration are most pronounced when high class direct consumption sugars are being made, and to this end they form an invaluable adjunct to the factory; it has also been found that they remove large quantities of suspended matter, and have a very useful effect in lessening the deposit of scale in the evaporators, and thus materially adding to their capacity.

Filtration through Wire Gauze.—A very useful effect is obtained by passing the juice through very fine wire gauze strainers; for this purpose a mesh of 100 strands per lineal inch is useful; the writer has seen high class consumption sugars made with the help of these strainers, with suppression of the cleaning of the juice by boiling in open pans.

Other Filtering Media.—In addition to sand many other filtering media have been proposed for use; amongst these may be mentioned megass, wood shavings, coke, chopped cork, pumice stone, slag wool, broken brick, lignite, gravel; of these the writer has seen fine wood shavings sold under the trade name of *Excelsior Packing* used with great success. When these media are used they are packed in vertical cylinders through which the juice is allowed to gravitate; the type of filter described under *Sand Filter* forms a very convenient pattern.

Composition of Press Cake.—The composition of press cake is shown in the following analyses due to Prinsen Geerligs :—

	Defecation Process.	Single Carbonation.	Double Carbonation First Saturation.	Double Carbonation Second Saturation.
Water	69·72	—	—	—
Sugar	10·20	3·90	10·10	8·10
Glucose	·71	—	·38	—
Wax	4·12	3·43	2·48	—
Albumen	1·80	2·55	2·72	—
Fibre	—	3·08	6·10	·50
Organic acids	—	1·94	2·12	4·20
Gums	—	1·11	1·20	—
Phosphate of lime	2·92	—	—	—
Silica	·37	8·48	1·85	·64
Iron and alumina	1·40	2·41	4·66	·51
Magnesia	·22	—	—	—
Sand and clay	2·82	2·48	4·37	—
Calcium carbonate	—	67·94	61·94	85·01
Magnesium ,,	—	1·80	1·21	—
Phosphoric acid	—	·71	·87	·12
Undetermined	5·35	·17	—	·82

CHAPTER XVI.

THE EVAPORATION OF THE JUICE TO SYRUP.

By evaporation is meant the passage of a body from the liquid to the gaseous state. The term evaporation is usually restricted to that change which takes place continuously at the surface of a liquid, and ebullition or boiling to that which takes place throughout the entire mass.

Evaporation takes place continuously at the surface of all exposed liquids. The molecules or particles of matter, of which all bodies are supposed to be composed, have in a liquid but little attraction for each other, and tend constantly to fly off into space. In an enclosed liquid a quantity of vapour will be formed above the surface. The molecules of the liquid, in the form of vapour, are in constant movement, and will in their paths to and fro impinge on the surface of the liquid, which is at the same time constantly giving off vapour; eventually a point is reached when as many molecules leave the liquid as enter, so that a system in equilibrium obtains. When this state is reached the space above the liquid is said to be saturated, and no more evaporation (apparently) takes place.

The vapour given off by a liquid exerts a certain pressure which increases with the temperature; this pressure is known as the vapour tension. When the vapour tension of the liquid is equal to the pressure of the surrounding atmosphere, bubbles of vapour form in all parts of the liquid, and the latter is said to boil; the boiling point of a liquid is then not a fixed figure, but is dependent on the pressure under which it occurs. The normal pressure of the atmosphere at sea level is equal to that exercised by a column of mercury 29·92 inches or ·760 metre high; this is equal to a pressure of 14·707 lbs. per square inch or to 1·034 kilogram per square cm. At this pressure water boils at a temperature of 212° F. or 100° C.; if the pressure be decreased the boiling-point of water of any liquid falls, and it is due to this phenomenon that multiple effect evaporating apparatuses can be constructed, in which 1 lb. of steam may evaporate in practice up to 5 or 6 lbs. of water. A table is added at the end of this chapter, giving data connecting the pressure and temperature of steam. The temperature at which a liquid boils is also influenced by the presence of bodies in solution; a table of the boiling-points of sugar solutions under atmospheric pressure will be found elsewhere.

Latent Heat.—When water or any liquid passes into the form of vapour, a certain quantity of heat is required to perform this change; this quantity is called the *latent heat of evaporation*. The heat required to raise the temperature of 1 lb. of water one degree Fahrenheit is called the *British Thermal Unit*, or *B.T.U.*, and to convert 1 lb. of water at 212° F. into steam at 212° F. requires 966 B.T.U. This quantity is the latent heat of evaporation of water. A quantity often used in calculation is the *total heat of steam ;* this means the quantity of heat required to convert 1 lb. of water from the freezing point (32° F. or 0° C.) to steam at the given temperature. Thus to raise the temperature of 1 lb. of water from 32° F. to 212° F. requires 180 B.T.U.; to convert it into steam requires 966 B.T.U., so that the total heat of steam at 212° F. is 1146 B.T.U. The metrical unit of heat is the quantity of heat required to raise one kilo. of water through 1° C.; it is called a Calorie, and is 3·967 times as large as the B.T.U.

Conversely to what has been written above, when steam is condensed to water it gives out the heat which was required to convert the water to steam. If then steam at 212° F. be condensed to water at 180° F. it gives up a quantity of heat which is the difference between the total heat of steam at 212° F. and of water at 180° F. This heat can be used to raise the temperature of or to evaporate water which is under such a pressure that its boiling point is lower than 180° F.; the vapour or steam given off by the water thus caused to boil may be used to boil more water under a still lower pressure, and so on, and this process repeated to infinity. It is on these lines that the construction of multiple effect apparatuses is based.

Standards of Pressure and Vacuum.—The normal pressure of the atmosphere is 14·707 lbs. per square inch and it will support a column of mercury 29·92 inches high; in the metric system the corresponding measures are 1·034 kilos per square cm., and a barometric height of ·760 metre. Pressures are also expressed in atmospheres and we thus have 1 lb. per square inch = 2·035 inches of mercury = ·068 atmosphere. The vacuum in an effect is nearly always given in inches of mercury; thus, a vacuum of 25 inches means that the excess of atmospheric pressure over the pressure in the effect would support a column of mercury 25 inches high; hence expressed as a pressure a vacuum of 25 inches means a pressure of 29·92 − 25 inches = 4·92 inches = 2·42 lbs. per square inch.

Transmission of Heat.—The coefficient of transmission of heat is the quantity of heat which will pass in one minute from a warmer to a colder surface of one square foot area under a difference in temperature of 1° F. The metrical units of reference are the square metre, degree Centigrade, and the calorie. The metric coefficient is then 4·88 times as great as the British coefficient.

The transmission of heat is governed by the following Laws :—

1. It is directly proportional to the mean difference of temperature.

2. It varies with the nature of the material through which the heat passes. The best conductors of heat are metals, silver and copper in particular; copper or brass are the two materials most used in practice.

3. The coefficient of transmission decreases with increasing thickness of metal; for copper, however, within the thicknesses employed in practice the coefficient is sensibly constant, and even with brass 5 per cent. would be an extreme variation.

4. The coefficient of transmission is affected by the nature of the substances on either side of the partition; thick viscid liquids as occur in the last body of a multiple effect greatly retard the passage of heat as compared with water. In an extreme case it may be only one-fifth of what it is when dealing with water.

5. Incrustations, such as occur on the tubes of a multiple effect, have an enormous and undeterminable effect in reducing the passage of heat.

6. The larger the heating surface, *i.e.*, the partition separating the substances between which a transfer of heat occurs, the less is its efficiency; that the efficiency is proportional to the square root of the surface has been established for tubes internally steam heated, and the same relation probably holds for externally heated tubes.

7. The transmission is also affected by the position of the heating surface; thus with vertical tubes the condensed water which is formed on the surface of the tubes flows down them and prevents intimate contact of steam and heating surface. With horizontal tubes the condensed water drops off the tubes and the latter are in general more efficient. Any form of apparatus which permits easy and rapid removal of condensed water is *per se* more efficient than one which does not fulfil those conditions.

8. The heat transmitted increases with the rapidity of circulation of the liquid being heated, and is greatly increased if the liquid should actually boil.

The proposition enunciated in *Law 1* requires some elaboration, and is only approximately true; the heat transmitted through a partition, one side of which is at 60°C. and the other 58°C. is twice as great as that transmitted when one side is at 60°C. and the other at 59°C., but it does not follow that in the latter case the heat transmitted is the same as when one side is at 120°C. and the other at 119°C., although the temperature difference is exactly the same. Actually, Claassen has shown that at higher temperatures the coefficient of transmission is much greater than at lower ones; hence it follows that a fall in temperature due to high vacuum in the last body of a multiple is not attended with so much benefit as in cases where the temperatures are more

elevated. Claassen[1] estimates that no practical benefit is obtained by increasing the vacuum in the last body above 60 cm. (= 23·7 ins.), as the decrease in the coefficient of transmission is sufficient to neutralize the increase in difference of temperatures.

The effect of the velocity of the juice has been experimentally studied by Porkong[2], whose data are as follows:—

With a velocity of juice 1·29 metres per second, the calories transmitted per minute and per square metre were, per 1° C. difference in temperature, 8·15, and with velocities 1·35 and 1·523 the corresponding calories were 16·25 and 17·71.

The coefficients of transmission under actual conditions have been studied by Jelinek and by Claassen[3]. Their results are given below:—

Triple	First vessel	37 calories.
	Second vessel	25 ,,
	Third vessel	14 ,,
Quadruple	First vessel..	28 ,,
	Second vessel..	26 ,,
	Third vessel	20 ,,
	Fourth vessel..	5-6 ,,
Vacuum pan	Graining	18 ,,
	Boiling	10 ,,
	Bringing up	3-7 ,,
Vacuum pan for low products		6-7 ,,
		(Jelinek).
Fore evaporator		50 calories.
Quadruple	First vessel..	45 ,,
	Second vessel..	30 ,,
	Third vessel	20 ,,
	Fourth vessel..	12 ,,
Reheating diffusion juices, carbonation juices and syrups		5 ,,
Vacuum pan first products		10 ,,
,, ,, low products		5 ,,
		(Claassen.)

The calories here given are metric calories. The low transmission coefficients found with heating juices as compared with those found with the juices in the evaporator are due to the fact that in the latter case the juices are actually boiling.

Superheated Steam.—Superheated steam is a much worse conductor of heat than is saturated steam, and hence the loss of heat in steam pipes is much less with superheated steam than with saturated; in addition, superheated steam can be used more economically in the cylinder of an engine

than can saturated steam; the very reasons that make superheated steam advantageous for use in engines prevent its satisfactory use for evaporation, where a rapid condensation and quick transference of heat is required.

Early Methods.—The earliest method of evaporation was in pots over a naked fire, a system still pursued by the ryots of India and on a fairly large scale in Barbados, the whole system of tayches being called a copper wall. The earliest improvement over this method was the introduction of steam-heated pans, followed by the *Aspinall, Wetzel,* and other devices; all these consisted essentially of an open pan in which revolved steam-heated coils or discs, so arranged that half the coil was immersed; the rotating coil carried upwards a thin film of liquid and thus exposed a large surface to evaporation.

In 1865, Fryer introduced the *Concretor,* a patent which has been extensively used. In this plant the thin juice flows over a series of trays placed over a flue, the whole being built on a slight incline; the flue is about
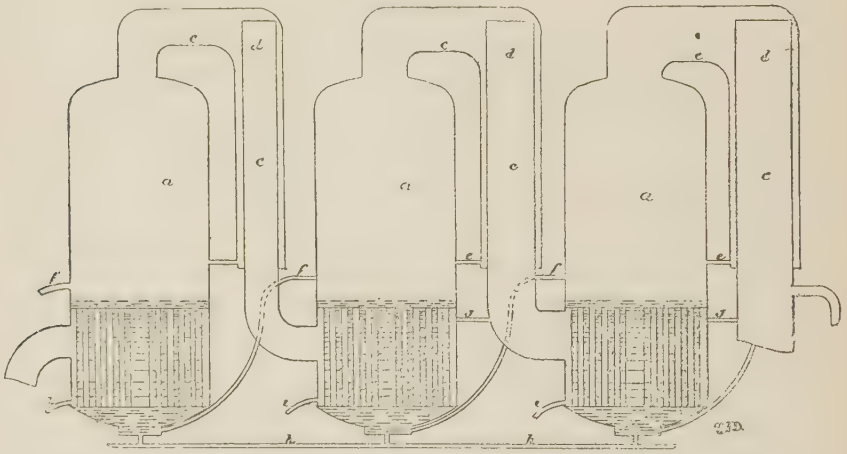
Fig. 157.

forty feet long and the juice travels in a zigzag path about two hundred feet; reaching the end at a density of about 50° Brix, it flows into a revolving cylindrical vessel, in the interior of which are fitted scroll-shaped plates, so that, as the cylinder revolves, a large surface is exposed to evaporation; at the same time a current of hot air is blown through. After twenty minutes' treatment in this cylinder the evaporated juice sets on cooling to a solid mass, and is shipped to refineries for further treatment.

A modernized form of this scheme is used in Miller's patent employed in the manufacture of 'basket' sugar in the Straits; the final concentration is effected by a revolving coil containing heated oil, the temperature of which can be regulated.

Multiple Evaporation.—In modern factories evaporation is always performed in multiple evaporators. The principle on which these are constructed has already been indicated. The first multiple evaporator was invented in 1834 by Norbert Rillieux, of Louisiana, and was a double effect horizontal submerged tube apparatus. Apparatuses conforming to his original design and only differing in mechanical details are still constructed.

In *Fig. 157* is shown a diagrammatic sketch of a vertical submerged tube triple effect apparatus. Each body consists of an upright cylindrical vessel of height rather more than twice the diameter; near to the bottom and at about one-third the height are placed two tube plates: these plates carry a number of tubes, the space between the tube plates and external to the tubes being filled with steam or vapour from a preceding effect; the vapours pass over from the juice in one vessel to the calandria of the next by means of the vapour pipe *c*. In each vapour pipe is often placed a cylindrical baffle plate *d* for the purpose of intercepting any juice carried over in entrainment: any juice so intercepted is returned by the pipe *e* to the vessels. The juice circulates from vessel to vessel by the pipes *f* under the influence of a difference in pressure or aided by a circulating pump; the concentrated juice from the last body is pumped out against atmospheric pressure; very often this pump is worked off the main vacuum pump. The water of condensation in the calandrias of the vessels passes out through the pipe *i*; generally steam traps of various constructions are used or the water may be removed by a small pump. In some designs the water of condensation is passed from vessel to vessel, affording a slight economy of heat. The pipe *h* is for the purpose of introducing acid or alkali to cleanse the tubes of scale and *j* is a small pipe carrying the incondensible gases from the second to the third vessel and thence to the pump.

The method of operation is as follows: juice is allowed to flow into the vessels from the supply tank until a little above the level of the upper tube plate; the vacuum pump is then started, and a vacuum of about 25 inches, corresponding to a pressure of about 5 inches, is obtained in the last body of the apparatus, and the water injection cock opened. Exhaust steam at a pressure of about 5 lbs. per square inch is admitted to the calandria of the first body; the juice boils and vapour passes over into the calandria of the second body, into which juice from the first body has already passed; the tubes in the second body act as a surface condenser to this vapour. The condensation of this latter creates a partial vacuum in the first body, and by its condensation parts with its latent heat to the juice in the second body, causing this juice to boil. A similar process takes place between the second and third bodies, and so on.

In this way 1 lb. of steam could evaporate an infinite quantity of water; for reasons explained later on, the practical working limit is generally granted to be reached with quadruple evaporation. The majority of apparatuses are, however, triple effects; but quintuple plants have been constructed.
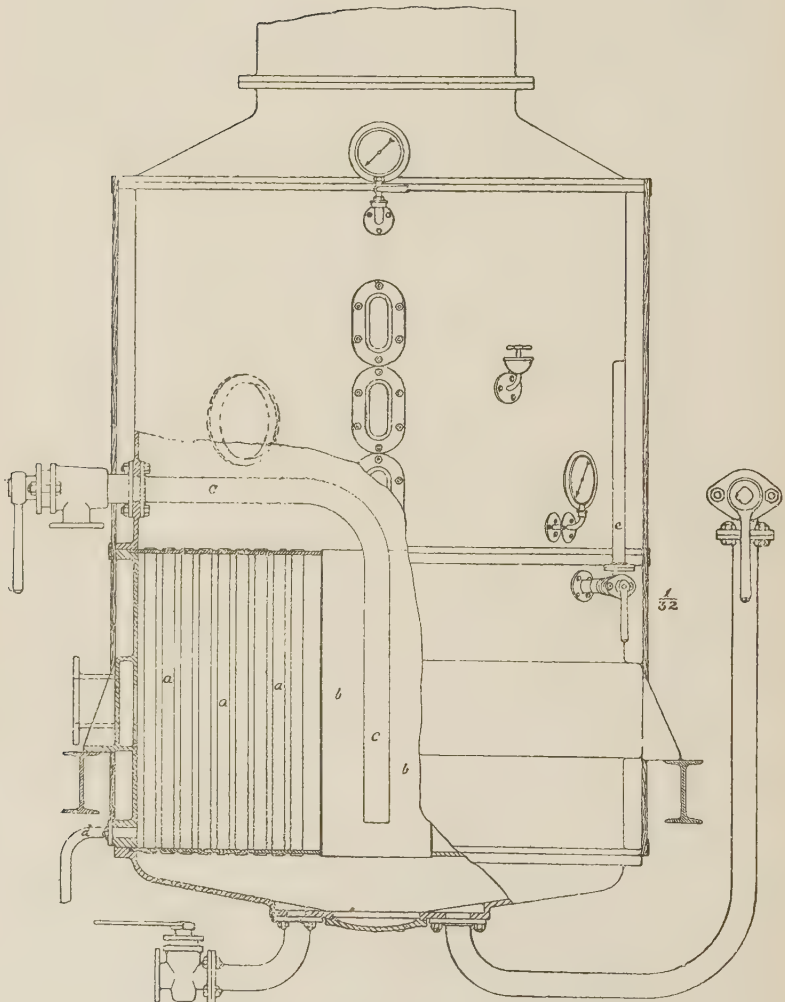
Fig. 158.

Apparatus for multiple evaporation may be divided into three classes:—

1. Vertical submerged tube apparatus, often referred to as the '*standard*' type.

2. Horizontal submerged tube apparatus, conforming to the original *Rillieux* and including the *Welner-Jelinek* apparatus.

3. Film evaporators, including the *Lillie*, *Yaryan*, and *Kestner* patents.

Vertical Submerged Tube Evaporator.— In *Fig. 158* is shown a section of one vessel of a vertical tube apparatus. At *a* are the tubes outside which circulates the heating steam, the juice being contained within the tubes and above and below the tube plates; at *b* is an opening in the centre of the tube plate forming a large central circulating tube; at *c* is the juice intake pipe dipping down to near the bottom of the vessel; at *d* is a pipe through which is drawn off the condensed water; at *e* is a pipe through which the incondensible gases are drawn off.
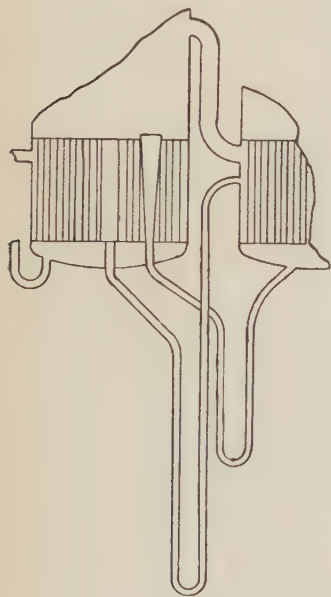
The Calandria or tubular cluster consists of two tube plates into which are expanded the tubes; the tube plates are usually fixed to the wall of the containing vessel, but in some designs the calandria has its own side walls, an annular space being then formed between the interior of the vessel and the exterior of the calandria. The large central tube is for the purpose of providing a circulation, and is very generally found; in other designs the circulating tube is not placed centrally, but at the side. The tubes are usually made of brass, but copper is sometimes used, and in some German designs the tubes are made of mild steel. The diameter of the tubes is generally about two inches; in earlier plants the length of the tubes reached up to as much as six feet or more, but now four feet is a usual length; it will be shown later that a great length of tube may be detrimental to the efficiency.

FIG. 159.

The distribution of the heating steam has a great effect on the efficiency; if the steam enter at one place only, that part of the heating surface remote from the steam entry tends to become inefficient, and there is also a tendency for incondensible gases to bank up. In the design shown the heating steam passes into a belt surrounding the calandria; in other designs the steam or

vapour enters the calandria in as many as six places. To further secure an even distribution of steam it is not unusual to divide the calandria into compartments by means of partition plates.

Stillman Evaporator.—This design externally resembles the 'Standard'; the tubes however project about 6 inches above the upper tube plate, and are up to 7 feet in length; the liquor level is kept at about half the height of the tubes: the juice creeps up the tubes, overflows on to the tube plate,
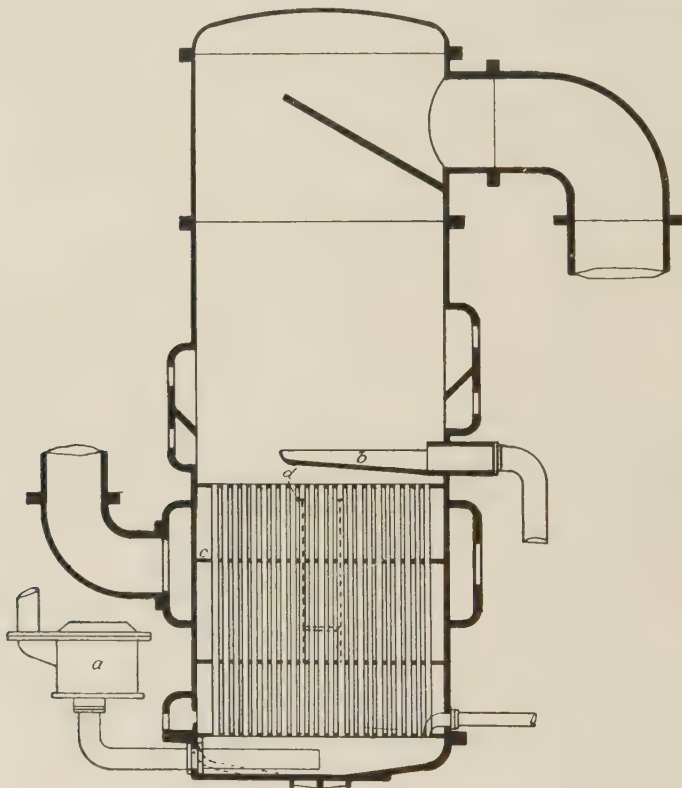
FIG. 160.

and passes down a central tube of large diameter to the next effect in series. This evaporator belongs to the 'film' type and has a high efficiency; the only one the writer has seen would have been improved by a larger vapour space.

Chapman's Evaporator.—Of special forms of the vertical tube evaporator, Chapman's design, *Fig. 159*, may be mentioned. The juice enters at *a*, and flows upwards through the tubes and down through the funnel *b*. In the form sketched the vessel is divided into two parts by a vertical partition, affording a double circulation; in others the juice passes directly from vessel to vessel. Circulation between the different bodies is obtained by means of

inverted syphons connecting the discharge of one with the intake of the next body, and these are of such a length that the leg connected with the second body is from 12 to 18 inches longer than the column of liquid which is due to the greatest pressure that can be possibly obtained between the two vessels. This apparatus is to a large extent self adjusting; there is only one cock to control the flow of the juice into the apparatus, and the system of circulation prevents the juice in any vessel rising much above the level of the tube plate.
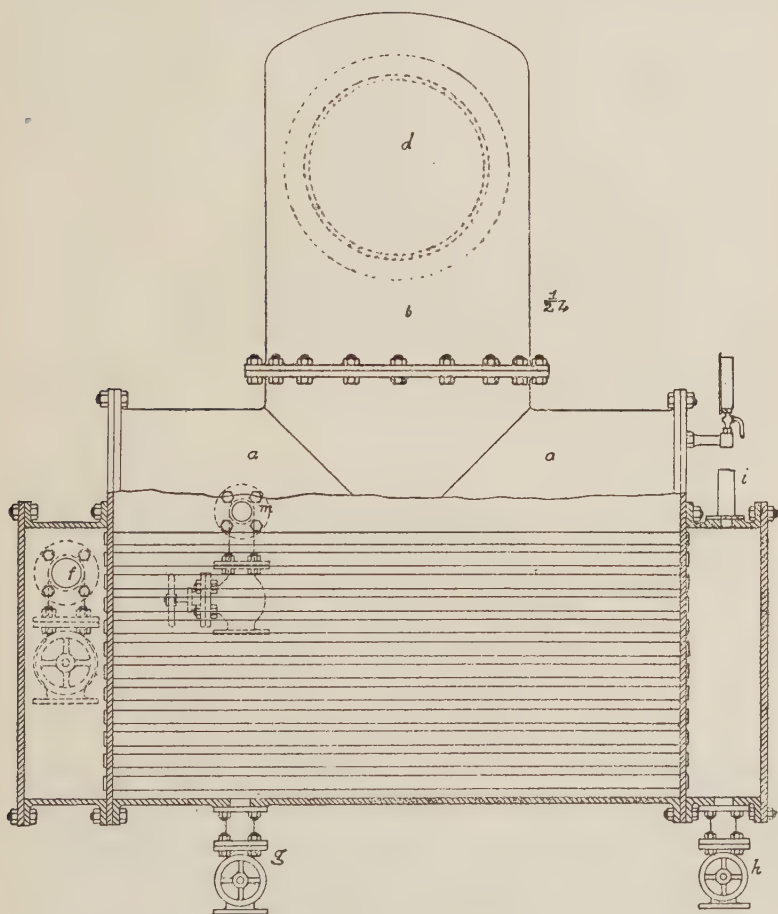
FIG. 161.

Hagemann Evaporator.—This specialized type of standard evaporator is shown in *Fig. 160*. The peculiar points in this design are the automatic regulation of the flow of the juice by traps *a* and by the juice trays *b* taking the place of the syphons in Chapman's design; the horizontal baffles *c* in the calandria ensure the action of the hottest steam at the upper level of juice and the vertical baffles *d* give an up and down circulation to the juice.

The Horizontal Tube Apparatus.—The horizontal submerged tube apparatus differs from the above in that the steam or vapour is contained within the tubes, the juice under treatment being outside; a longitudinal section of this form is shown in *Fig. 161.* The evaporating tubes are from 5 to 6 feet long, and are supported by vertical tube plates placed about 12 inches from the end; steam enters at the side at *f*, passes through the tubes, and after condensation is trapped at *h*; to facilitate the passage of the water the tubes are often set at a slight incline. It will be seen that the level of the juice in the vessels is, relatively, much higher than in the vertical type. To prevent entrainment losses a very capacious steam chamber is placed over each vessel; the vapour main leads from this steam chamber to the calandria of the following effect. Plants of this type are not usually made by English firms, who prefer the vertical form; they are made to a certain extent in America, and are very largely used in Austria and Russia.
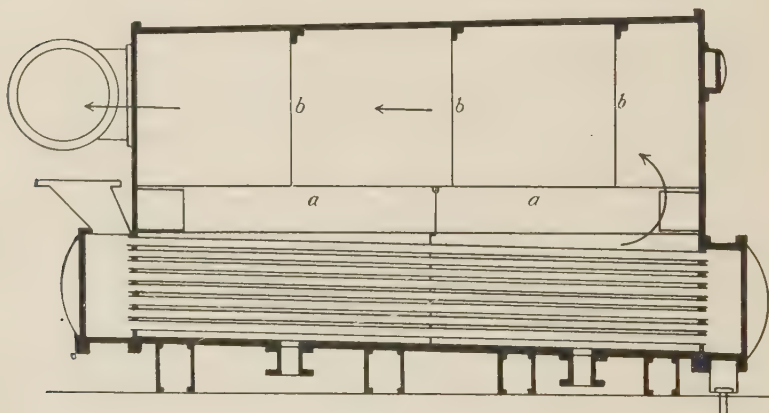
Fig. 162.

In this type of evaporator the incondensible gases are swept forward by the steam and collect in the space at the end of the tube run, whence they are removed through *i*; removal of the gases is much easier in this form of apparatus than in the vertical tube design.

In *Fig. 162* is shown a longitudinal section of a cylindrical Rillieux apparatus, as made by the Newhall Manufacturing Co.; it differs from other plants in the low vapour space above the boiling liquid; losses due to entrainment are prevented by the horizontal baffle plate at *a a* and by the vertical plates at *b b*; these last extend only half-way across the shell and are attached alternately to opposite sides. This apparatus conforms very closely to the original Rillieux design.
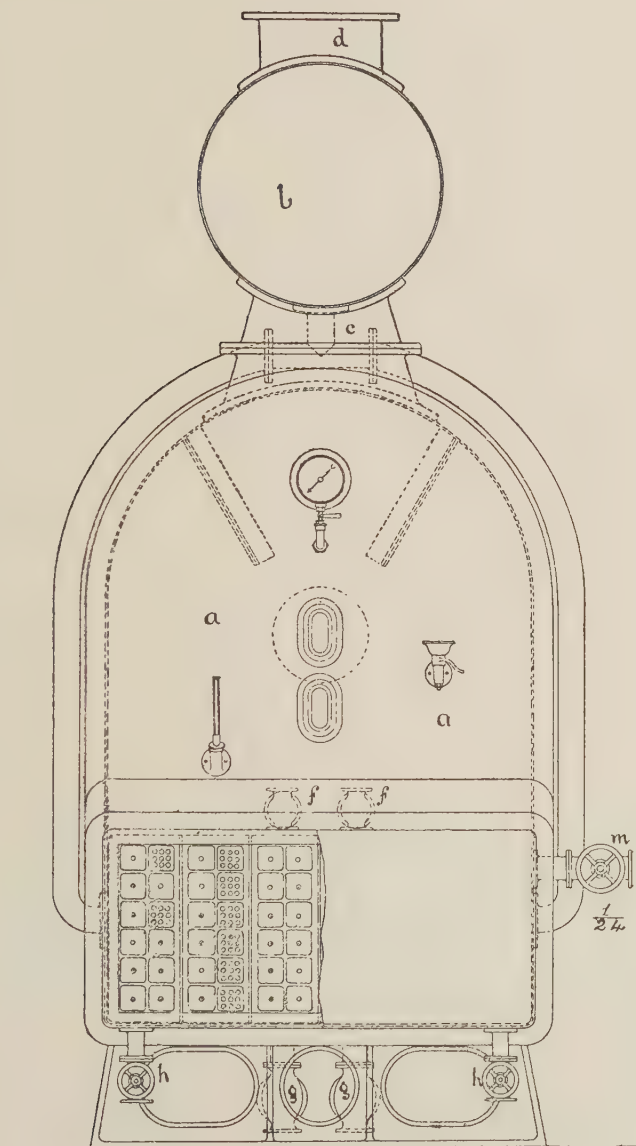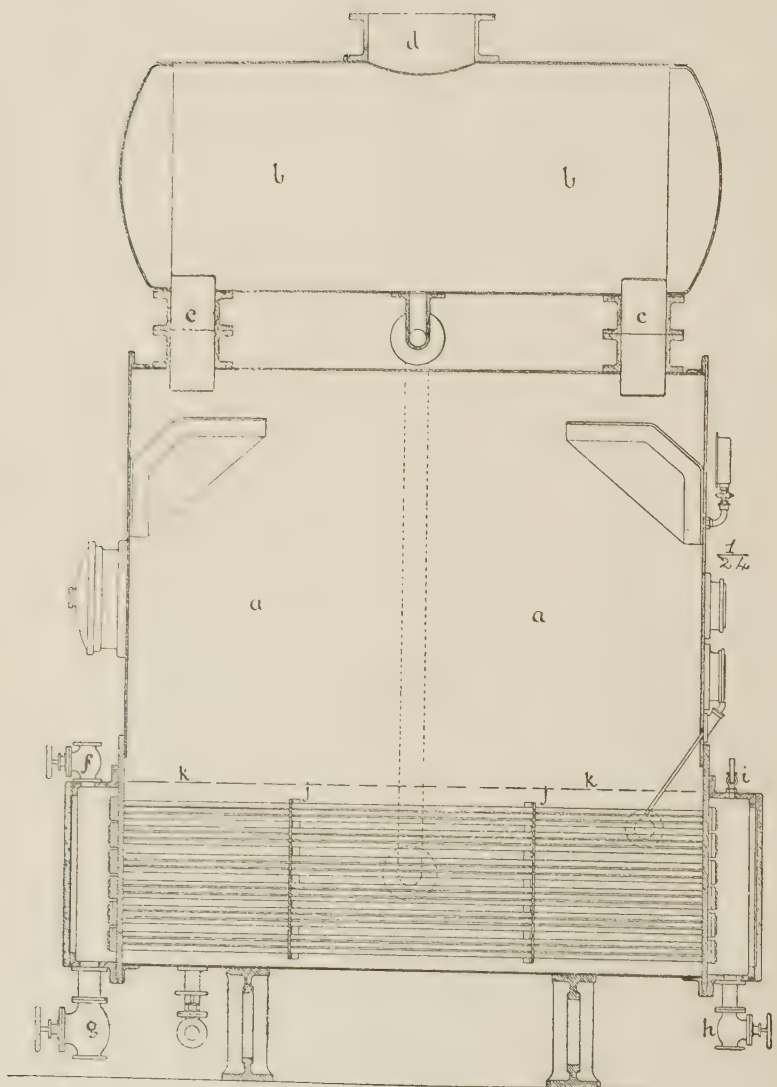
Fig. 163.

FIG. 164.

The Welner - Jelinek.—The *Welner-Jelinek* evaporator is a horizontal submerged tube apparatus differing very materially from the above, and is designed initially to have the height of the column of liquid under treatment as small as possible; the evaporating tubes are shown in end elevation and longitudinal section in *Figs. 163* and *164.* They are about twelve feet long and three-quarters of an inch in diameter; they are supported by tube plates at either end and by two intermediate tube plates shown at *j*; the tubes are generally arranged in nests of nine. The length and small
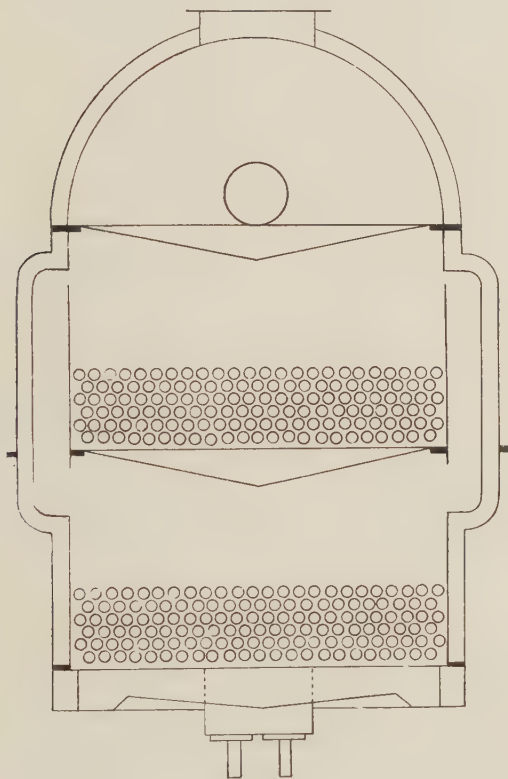
Fig. 165.

diameter of the tubes necessitates the use of the intermediate tube plates, but at the expense of the longitudinal circulation. On reference to the drawing, *Fig. 164,* it will be seen that the steam or vapour entering at the valves *f* circulates through three sets of tubes; the rush of steam carries the condensed water along with it, the latter being trapped at *h* in the boxes at the end of the run. In some designs the condensed water is also trapped in the return boxes. The level of the juice under treatment is shown at *k*, the vertical height being only from 22 to 24 inches. The juice enters at *m* and leaves by

the pipe g; a minute air vent is placed in the condensed water box at i. Above the main vessel, and communicating with it by two pipes c, is placed a save-all b, from which passes the vapour pipe to the next effect. Compared with the horizontal apparatus of the Rillieux type, the relatively small height of the column of juice, the large vapour space, and the method of steam circulation, are to be noted. This type has been extensively used on the Continent of Europe, and especially so in Austria.

Swenson Evaporator.—This evaporator follows the general form of the Welner-Jelinek, from which it may be regarded as derived; the tubes are not expanded into the tube plate but a tight joint is made by means of rubber rings.
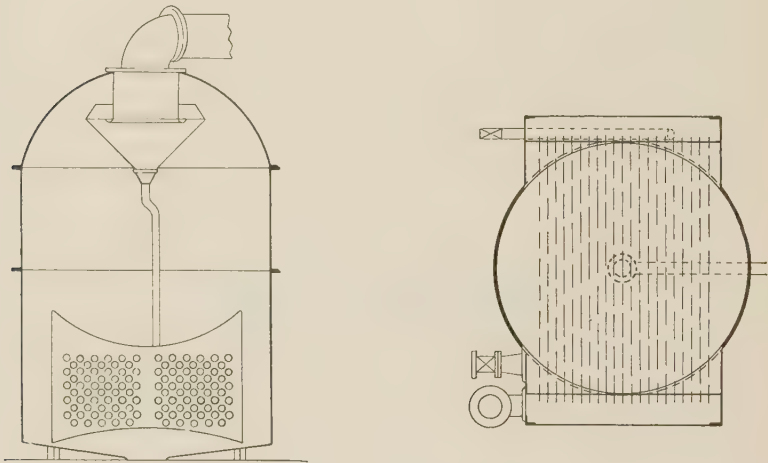
Fig. 166.

Stage Evaporation.—In order to minimize the effect of the hydrostatic pressure (*cf. infra*) the heating surface of the horizontal tube evaporators is sometimes divided into stages whereby a low level of juice is obtained: this method is shown in *Fig. 165*, which represents a section of a *Newall* horizontal tube apparatus. Each stage has its own juice connections and separate vapour intake; the vapours from the stages combine, those from the lower stage passing upwards between the shell and the upper stage. In the *Welner-Jelinek* and *Swenson* patterns the vapour uptake from the lower stage is arranged through a passage in the centre of the upper stage.

The Zaremba Evaporator also may be regarded as derived from the Welner-Jelinek: the shell of this apparatus is a vertical cylinder, a calandria of rectangular section being arranged in the lower part. This apparatus is shown diagrammatically in *Fig. 166*.
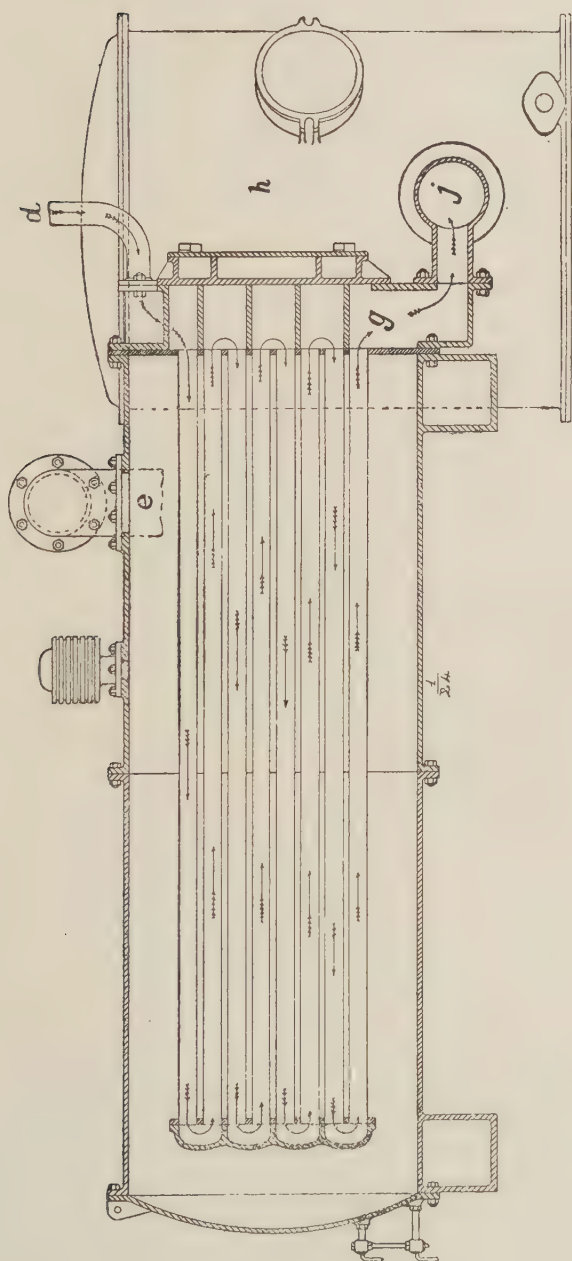
Fig. 167.

The Yaryan.—The Yaryan evaporator, shown in longitudinal section in *Fig. 167*, and in end sectional elevation in *Fig. 168*, consists of a horizontal body or shell of steel plate or cast-iron—depending upon size and steam pressure—within which is grouped a series of tubes about 3 inches diameter ; these tubes are expanded into the tube plates as shown, and at each end 'return heads' are bolted on, thus forming a connection which ensures the continuous flow of the liquor through each coil or tube system.

Steam, or vapour from a preceding shell or effect, enters the shell at *e* and surrounds the outside of the tubes containing the liquor to be evaporated.
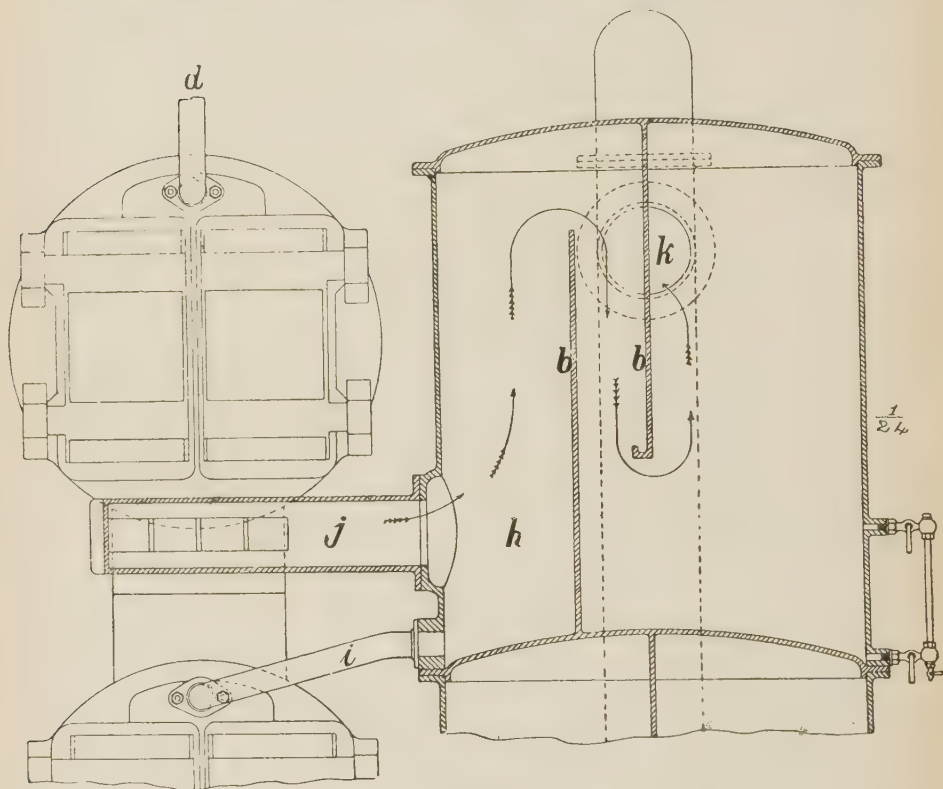
FIG. 168.

The liquor entering pipe *d* is forced, under pressure by a pump or otherwise, into the top tubes, and only partially fills their bore, thereby allowing space for the vapour arising from the heated liquor to pass freely away. The liquor passes along with a rapid and continuous motion through the series of tubes and discharges at *g*, the concentrated liquor and its vapour, passing along pipe *j*, falls into the separator *h*, shown in section in *Fig. 168*. The vapour passes, as indicated by the arrows, up and down the two baffle plates *b b*, where it emerges into pipe *k* which leads direct to shell of next vessel, or to condenser if from the last effect.

The concentrated liquor falls to the bottom of separator *h* and passes along pipe *i* to the next shell for further concentration, and so on until, sufficiently concentrated, it has reached the last effect, when it has then to be pumped out owing to its being treated in a vacuum.

The Lillie.—The *Lillie* horizontal tube film evaporator offers a system of evaporation radically distinct in mechanical details from any of the above. A vertical longitudinal section is given in *Fig. 169*, and in *Fig. 170* is shown an end elevation. The evaporating tubes are 5 to 6 feet long and 3 inches in
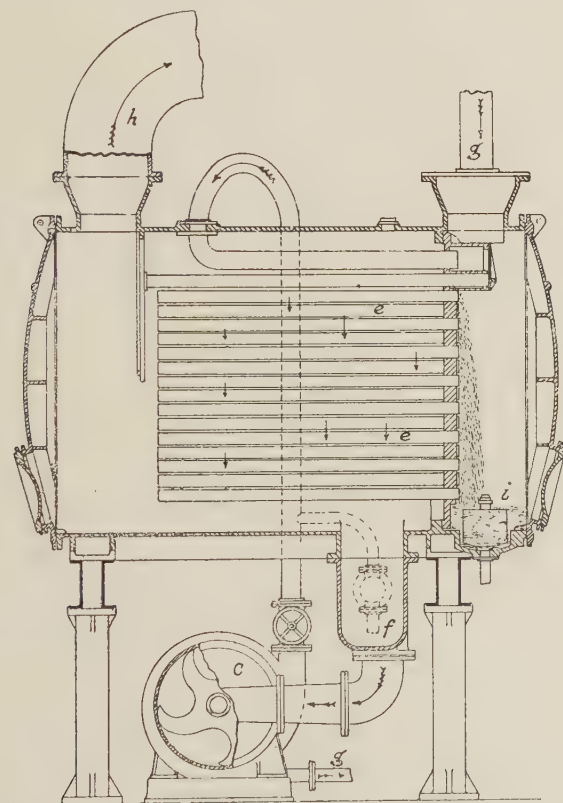
FIG. 169.

diameter; they are expanded into a tube plate at one end only to allow free expansion and are set at a slight incline to afford easy escape of condensed water; each tube has its own air vent at the end opposite to the tube plate. The juice is circulated by means of centrifugal pumps *c* all worked off one shaft; these pumps are of sufficient power to force the syrup out against atmospheric pressure. The supply of juice enters through the balanced valve operated by the float resting on the surface of the liquor in the float box *f*, and which permits the thin liquor to enter the effect and be added to the circulating

liquor just fast enough to replace that passing away as vapour and through the discharge. The latter is controlled by the hand valve g; by opening it the discharge is increased, causing the level of the liquor in the float box to fall, and admitting a larger feed. The path of the juice is from the float box, through the pump and connecting piping up into the manifold box on the back of the tube plate, thence into the several distributing tubes through the slots of which it passes as a fine shower over the evaporating tubes to the float box to again make the same journey, part passing through the discharge pipe to the next effect. The steam enters by the pipe g, passes inside the tubes, the condensed water flowing down and being trapped at i, whence it passes on
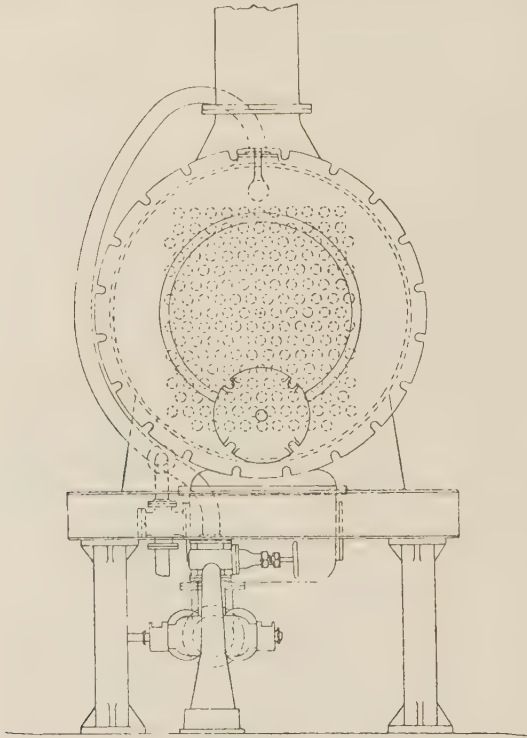
Fig. 170.

to the next effect, the evaporated vapour passing by way of h to the following body. The *Lillie* evaporator differs from others in the following points. The juice under evaporation is always in a state of film or rain, and hence there is no tendency for the boiling point to be elevated through the pressure of a column of liquid and thus to diminish the efficiency of the heating surface. The quantity of juice in process of evaporation at one time is very small and is consequently under treatment but a short time. The state of subdivision of the juice allows a free and easy disengagement of vapour without spurting and tends to diminish entrainment losses.

The Kestner Evaporator.—This type of evaporator is radically distinct from all the forms previously described, and is the last development of the principle of '*ruisellement*' or '*grimpage.*' It is a vertical tube externally heated film evaporator, and consists of a vertical tubular calandria, *Fig. 171*, with tubes about 23 feet long; the juice under evaporation is contained in the tank *x*, and passes by the pipe *T* to the interior of the tubes, which are from 1·5 to 3 inches in diameter; the heating steam enters the shell at *A*, and the formation of vapour within the tubes causes the liquid undergoing the treatment to climb upwards in the tubes; at *D* is shown a centrifugal separator designed to prevent entrainment.
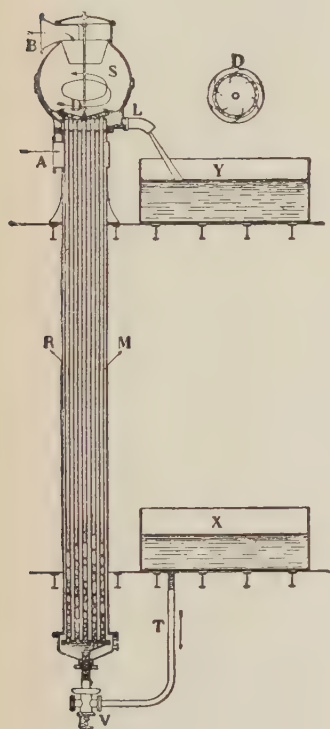
It is claimed for this apparatus that the coefficient of transmission of heat is very great and that owing to the juices being but a short time under treatment it is especially adapted to be used as the pre-evaporator in the Pauly-Greiner scheme of heat utilization described below.

Van Trooyen[4] gives the following particulars of a Kestner quadruple at 'Pasto-Viejo,' Porto Rico. Each body is a vertical cylinder 24 feet high and 3 feet 6 inches in diameter, made in two pieces with an expansion joint; the separating chamber is 7 feet in diameter and 6 feet high, except in the last body where it is seven feet high. The heating surface in the first three vessels consists of 250 tubes, 23 feet long and 1½ inches outside diameter; in the fourth vessel there are 130 tubes, also 23 feet long and 2¾ inches diameter. The heating surface in the whole apparatus is 8144 square feet. The pumps are of the following dimensions :—

	Air. Inches.		Juice. Inches.		Water. Inches.
Stroke	20¾	....	10⅜	....	10⅜
Steam cylinder	10¾	....	7¾	....	12½
Pump cylinder	23	....	4½	....	12½
Revolutions	46	....	—	....	—

The syrup is removed from the last body by means of a barometric fall pipe.

Witcowitz Heater.—In *Fig. 172* is shown in section the radiating heater of Witcowitz. It consists of a forged steel body, *aa*, through which pass at right angles to each other a series of tubes, *bb*. The juice circulates through these tubes, the heating steam being without the tubes and within the steel body ; the condensed water and heavier gases are drawn off at *c*, the lighter ammoniacal gas at *d*. A very rapid circulation is claimed for this design ; it is usually applied to the horizontal form of evaporator described above, and is also used as a heater in saturation and defecating tanks, and is capable of application to the vertical form of evaporator.

Express System.[5]—Another modification of the heating surface, known as the 'Express' system, is shown in section in *Fig. 173*. It consists of a belt, *aa*, in which are arranged the tubes which form the heating surface ; as in the Witcowitz heater above described, the juice circulates through the tubes *b*, steam entering the collector box at *c*, and the condensed water passing away at *d*. The collector box is set at an angle following the slope of the saucer of the effect, usually at an angle of about 30° from the horizontal; the tubes are about 18 inches long. In an effect entirely on this system there will be a second calandria above the one shown and placed in regard to it as a mirror image to the object. This design can be readily applied to effects with the ordinary vertical tube calandria, a belt being added to the effect below

FIG. 172.

the existing calandria in which the additional heating surface is placed.
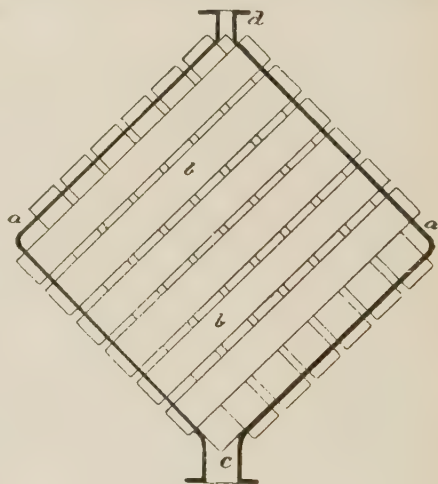
The 'Express' system has been further developed by placing within the shell of a vessel an inner shell of the same diameter as the calandria and leaving a space of some inches between the two walls; a colder and heavier liquor collects here, which tends to descend and thus to form an induced circulation.

Incondensible Gases.—In the process of evaporation a certain quantity of incondensible gas is formed, and in addition some air enters with the steam and through leaks in the apparatus. These gases have a corroding effect on the apparatus, and if allowed to accumulate seriously diminish the efficiency of the heating surface. In the first vessel they may be removed by a cock opening into the atmosphere, but as steam also will pass out, this process is uneconomical, and it is preferable to pass the gases successively

from vessel to vessel and finally to the condenser of the pump. The pipe collecting the gases should be placed as remote as possible from the steam or vapour inlet ; it is quite usual to find the gases collected in three or four places, the several pipes afterwards uniting into one. The pipes collecting the gases should be arranged flush with the top tube plate, and should not project beneath it, else opportunity will be given for the gases to accumulate.

Condensed Water.—The condensed water from the first vessel is used in the boilers, and there being a pressure in the calandria of the first vessel it does not require to be drawn off by a pump, but may be passed through a steam trap. The condensed water from the second and subsequent vessels must be drawn off by a pump, and its rapid evacuation has a considerable effect on the efficiency of the apparatus. This water is not suitable for use in boilers, and is generally employed in maceration. A small heat
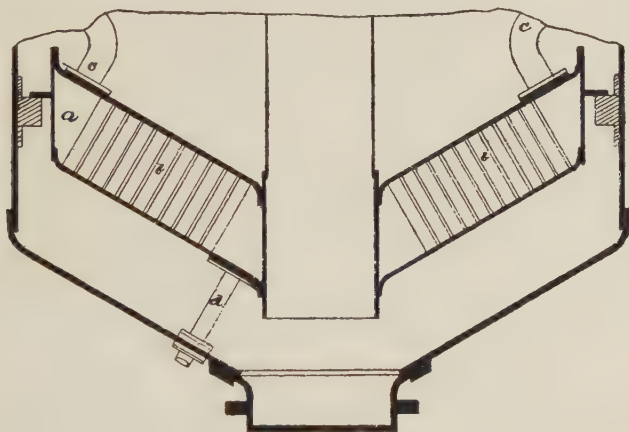
FIG. 173.

economy is obtained by passing the condensed water of the second vessel through the calandrias of the third and subsequent vessels. In certain instances a pump for drawing off the condensed water is dispensed with, the water being trapped and passed into the main pump ; this scheme is not to be recommended, both on account of diminishing the efficiency of the pump, and also as losing a valuable supply of hot water.

Distribution of Steam in the Calandria.—The earlier types of apparatus were provided with only one pipe for carrying steam to the calandria, resulting in an uneven distribution of steam ; the later apparatuses distribute the steam by any of the following devices :—

(*a*) The arrangement of baffles in the calandria causing the steam to follow a zig-zag course ; these baffles may be horizontal or vertical ; in one design a baffle following a helical course is used, the steam entering at the side and being conducted to the centre of the vessel.

(*b*) A steam belt completely encircling the calandria.

(*c*) Division of the main steam or vapour pipe into two or more branches, which may lie in the same horizontal or vertical plane, or four branches may be used, two in the same horizontal and two in the same vertical plane.

(*d*) The use of an internal vapour pipe passing down through the lead box of a vessel and connecting with the calandria at the position often occupied by the central juice circulating tube; in this design an annular space is arranged between the calandria and the shell of the vessel.

Circulation of the Juice.*—The circulation in an evaporator may be either positive or induced; the former when the circulation is obtained by means of pumps withdrawing juice from and returning it to a vessel and the latter when the circulation is obtained by the skill of the designer. In the earlier evaporators the central circulating tube (shown in *Fig. 158*) was absent and circulation too was restricted; the addition of this tube probably acts in the following way. Owing to the absence of heating surface the juice therein contained is cooler than that in the tubular cluster and tends to sink; its place is taken by hotter juice from the tubes and a regular circulation from centre towards the periphery is induced. In some apparatus the tube is placed at the side remote from the steam entry and it may be replaced by a space formed by cutting away a segment of the calandria on the side remote from the steam entry. The circulation so induced may be aided by asymmetry in the design of the shell;

Fig. 174.

thus the saucer instead of sloping equally in all directions may be bellied on one side.
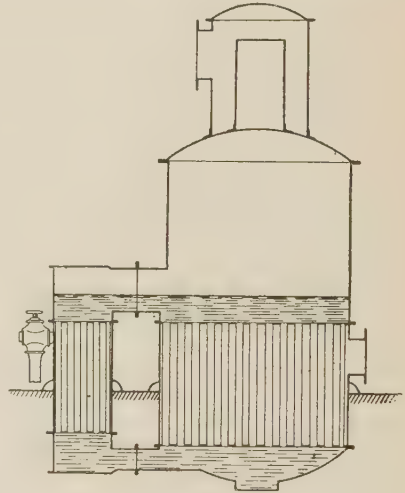
The utilization of temperature difference to induce a circulation has been further developed by the combined use of live and of exhaust steam; in Heckman's circulator, *Fig. 174*, a small tubular cluster is arranged without, but connected to, the main calandria, and is heated with live steam; in Rohrig's and König's design live steam is also used, the calandria taking the form of a small annular cluster arranged symmetrically with the vertical axis of a vessel.

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* Just before sending his MSS. to the press the author read Prof. Perry's *The Steam Engine;* in Chap. XXXIII. (edition of 1907), entitled "How Fluids give up Heat and Momentum," he discusses the importance of circulation of both hot gases and water as affecting the efficiency of the boiler: between the evaporator and the boiler there is a difference of degree only; his remarks on boilers are equally applicable to evaporators and should be studied carefully by all sugar house engineers.

Ruissellement.—By this term is meant the evaporation of juices in films as opposed to evaporation in bulk. It will be shown later that a high level of the juice undergoing evaporation is not conducive to a high efficiency, and further in bulk evaporation the body of juice under treatment at one time is great and may represent up to two hours' output of the mills. To overcome this disadvantage of the vertical tube apparatus many appendages to and various forms of tubes have been invented with the object of maintaining a film of liquid on the interior of the tubes. None of these devices have come into permanent use, as from their nature they prevented the cleaning of the
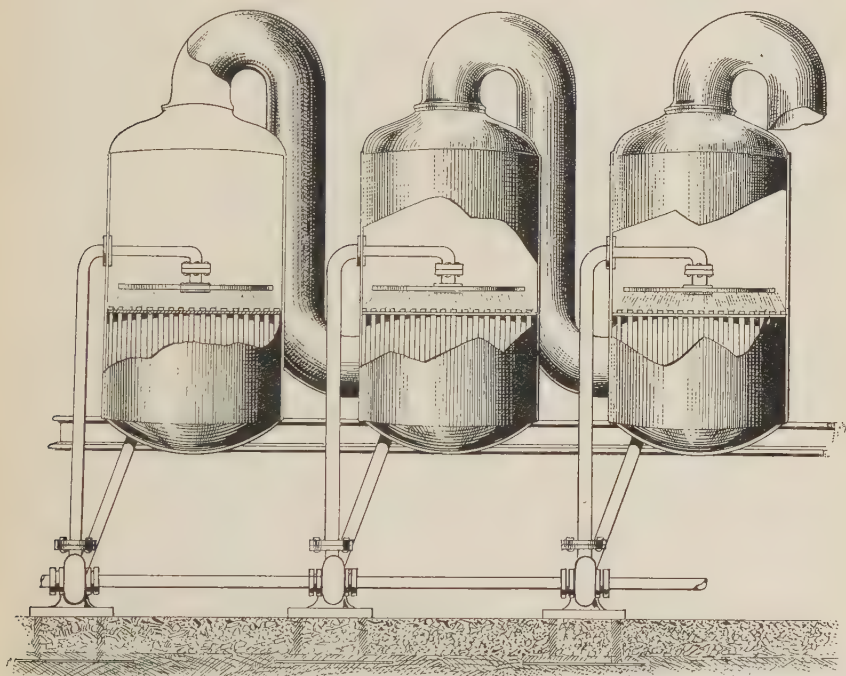
Fig. 175.

tubes. *Ruissellement*, or film evaporation, has, however, been successfully applied in the Yaryan, Lillie, and Kestner designs, and has been adapted to the vertical tube apparatus in the Meyer and Arbuckle patent; this process is shown schematically in *Fig. 175.* The circulation of the juice is effected by the centrifugal pumps; the juice on entering the pipe emerges as a spray through perforations in the latter and at the same time causes the pipe to revolve in a horizontal plane; the action is exactly similar to the sprinklers commonly used in watering lawns.

Film evaporation may to a certain extent be obtained in vertical tube apparatuses by keeping the level of the juice one-third to one-half the height

of the level of the upper tube plate; the contained juice creeps up the sides of the tubes, and in this form permits a rapid exchange of heat. Claassen's observations give the following coefficients of transmission :—

Tubes full .. .. 2·50
Tubes two-thirds full .. .. 3·00
Tubes one-third full .. .. 3·60
Ruissellement .. .. 2·90

Entrainment.—By entrainment is meant the carrying over of sugar along with the vapours and its consequent loss. Entrainment may take place in two distinct ways : in the first case the loss is entirely mechanical, and is due to splashing following on a vigorous ebullition, particles of juice being projected into the vapour pipe of the vessel. In the second case, loss is caused by vesicular transference ; by this term is meant the formation of bubbles of liquid, which being very light in proportion to their bulk are readily carried forward with the stream of vapour.
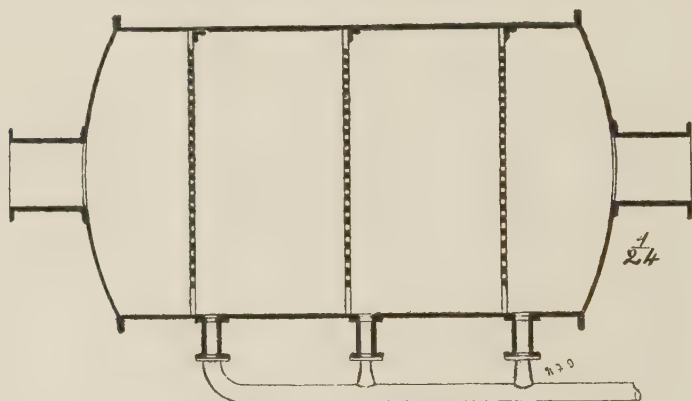
FIG. 176.

The first cause of entrainment is capable of control; the more vigorous the ebullition the greater is the height to which particles of juice will be projected ; with vessels having tubes of great length bubbles of steam formed at the lower layers will burst with greater force on reaching the vapour space than where the tubes are shorter ; further, tubes of short length imply vessels of large diameter and consequently a less velocity to the current of vapours moving forward to the next vessel. Losses due to splashing may be entirely prevented by the use of baffles, and better still by an ample vapour space.

The best known contrivance to prevent loss in vesicular transference is the Hodek *Ralentisseur*, Fig. 176, very extensively used in the beet sugar industry, but not often found in cane sugar factories, the island of Mauritius being an exception, and upon which many other designs have been based. The Hodek *Ralentisseur* consists of a vessel of considerably greater diameter than the vapour pipe, and of length generally about twice its diameter; it is

interposed in the vapour pipe connecting any two bodies, and is placed in either a horizontal or vertical position; placed in the vessel are perforated diaphragms, generally three in number, the sum area of the perforations being greater than the area of the vapour pipe; the diaphragms are sometimes dispensed with. Horsin Déon[6] states that as the most appropriate dimensions the *Ralentisseur* should be 3·5 times the diameter of the vapour pipe, and that the length should be twice the diameter.

The action of this apparatus is two-fold; the sudden increase in area of the pipe decreases the pressure of the vapour, so that the external pressure on the bubble is diminished and the latter bursts; in addition, there is the effect of the shock the bubbles suffer on striking on the walls of the diaphragms.

A sudden change in direction has also been observed to diminish entrainment losses, and vapour pipes are sometimes supplied with an enlarged section in which the direction of the vapour is twice abruptly changed by means of baffle plates.

A second form of entrainment preventer, the patent of Messrs. John McNeil & Co., is shown in *Fig. 177.* Within the dome-shaped cover *a* of the
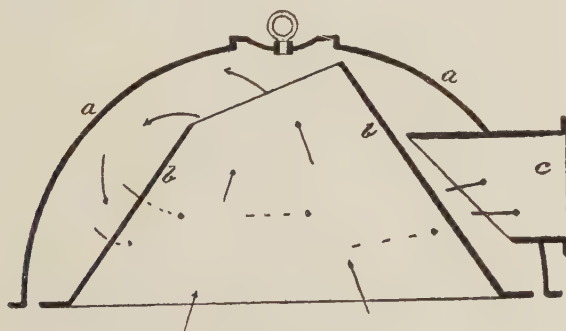
FIG. 177.

effect or pan is arranged a conical vessel *b*. The orifice of this funnel is pointed in the direction opposite to the pipe leading to the next effect or to the condenser. Particles of juice are projected on to the roof and thence fall on to the sides of the cone, and the vapour in its passage round the cone also deposits particles of liquid. The condenser pipe *c* projects inwards to prevent these particles from being swept forward with the current of vapour.

In the factories with which the writer has been connected entrainment losses were so small that it was practically impossible to estimate them, and it was only in waste water from the last vessel of the evaporator that sugar could be detected, and then not by any means always.

Fries[7] in Hawaii ingeniously placed small pipes in the vapour pipes of the effects and pans and measured the sugar there collected over definite periods; he found a loss of ·006 per cent. in the pans, and a variable loss of ·002 per cent. to ·008 per cent. in the evaporators.

The writer has found, however, in evaporators of old design, with small vapour spaces and pipes of restricted area, losses amounting to 2 per cent. of the sugar entering the boiling house.

Theory of Multiple Evaporation.—The theory of multiple evaporation in vacuo has been elaborated by Jelinek, Horsin-Déon, Dessin, Claassen, Bolk, and Hausbrand; the most complete and elegant theory is that due to Hausbrand[8]; in what follows, the writer is indebted to all these experts, and especially to the last mentioned.

It may be stated at once that it is impossible to calculate on first principles the pounds of water evaporated in each body of a multiple effect, unless the different temperatures in each body are assumed. The temperatures, however, depend on a number of factors—the temperature of the heating steam, the vacuum in the last body, the height of the liquid under treatment, &c., all of which are variable or unknown. Very considerable information can, however, be obtained on the lines below.

In a simple unexact way it is understood that a pound of steam introduced into the first body evaporates there a pound of water, the resulting steam passing on to the second body again evaporates a second pound of water and so on; but this supposition is only approximate.*

In the first instance, as the temperature at which evaporation occurs decreases, the latent heat increases, so that for this reason the steam from an earlier vessel evaporates less than its own weight of water in the succeeding one, but on the other hand the liquid entering from an earlier vessel itself suffers a fall in temperature and the heat given up can go only towards the formation of steam. Water evaporated by reason of this last cause is termed *self-evaporation*. As a numerical example the following data may be taken: 100 units of water enter the first vessel and from it are evaporated 25 units of water, so that 75 units pass on to the next vessel. Let the temperature in the first vessel be 212° F. and in the second vessel be 194° F.; the latent heats of steam at the two temperatures are 966 and 978 B.T.U. respectively. The 25 units of steam will then evaporate by their condensation $25 \times \dfrac{966}{978} = 24\cdot7$ units of water. But the water in cooling down from 212° F. to 194° F. gives up $75\ (212 - 194) = 1350$ units of heat; this quantity will evaporate $\dfrac{1350}{978} = 1\cdot4$ units of water. This latter is the self-evaporation and the total evaporation is $24\cdot7 + 1\cdot4 = 26\cdot1$ units. Another cause tends to make the

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* It should be pointed out that the evaporation in a multiple evaporator is best expressed as water evaporated per lb. of steam received + steam used in driving the vacuum pump; actually most of the direct steam admitted to the cylinder of the pump passes out as exhaust, the heat of which is utilized in evaporation, but the steam condensed in the cylinder + that represented by the fall in total heat of the portion which passes out, should be added to the steam condensed in the calandria of the first effect when estimating the evaporation per lb. of steam. Since a quadruple of equal capacity with a triple will require a smaller pump, the economy of the former compared with the latter will tend to be greater than in the ratio 4 : 3.

evaporation greater; the steam or vapour which has induced evaporation flows away, not at the temperature which it possessed when in the form of steam, but at the temperature which prevails in the lower part of the calandria where it is condensed; however the evaporation on this score is barely appreciable.

By a system of trial and error, Hausbrand has calculated the actual evaporation in each vessel of a double, triple, and quadruple effect for a large number of differently divided temperatures, for evaporations 90 per cent. and 75 per cent. of the original weight of the liquid, and from the results of his calculations he has demonstrated that of the total quantity of water evaporated in any vessel, that portion evaporated by heating (apart from self-evaporation) is very constant, and that the total evaporation in any such vessel is very much of the same order.

The five conclusions drawn by Hausbrand are :—

1. The smallest amount of heating steam required to produce a certain amount of evaporation is used in all evaporators when the fall in temperature is the same in each vessel.

2. However the fall in temperature in the separate vessels be arranged, the weight of heating steam to be supplied to the first vessel varies always within very narrow limits. Thus the manner in which the available fall in temperature is distributed amongst the separate vessels has no great influence upon the economy of steam. No considerable saving in steam can be obtained by any definite division of this fall in temperature.

3. The quantity of water to be evaporated in the first vessel is on an average of the total evaporation : —

$$\text{In the double effect } \frac{1}{2 \cdot 147} = 0 \cdot 466.$$

$$\text{In the triple effect } \frac{1}{3 \cdot 333} = 0 \cdot 300.$$

$$\text{In the quadruple effect } \frac{1}{4 \cdot 626} = 0 \cdot 216.$$

The extreme cases are :—

For the double effect $0 \cdot 434 - 0 \cdot 484$.
For the triple effect $0 \cdot 2777 - 0 \cdot 3152$.
For the quadruple effect $0 \cdot 1926 - 0 \cdot 2335$.

4. The evaporation effected by heating* is in all cases the least in the first body, but the increase in the following vessels is not very great, at most 4 per cent. In the mean it may be assumed that this evaporation in the separate vessels is in the

Double effect 1 : 1·045.
Triple effect 1 : 1·01 : 1·04.
Quadruple effect 1 : 1·005 : 1·012 : 1·02.

---

* Steam produced by self-evaporation in the second body evaporates water by heating in the third; these figures do not include water evaporated by heating on this score.

5. The total quantity evaporated in the last vessel is

In the double effect 0·534.

In the triple effect 0·3734.

In the quadruple effect 0·284

of the total evaporation of the apparatus.

In the mean the evaporative capacity of each vessel, not including self-evaporation in the vessel, but including the evaporation due to heating from self-evaporation in a previous vessel, is in

Double effect 1 : 1·0045

Triple effect 1 : 1·0075 : 1·138.

Quadruple effect 1 : 1·0055 : 1·109 : 1·196.

Hausbrand uses the figures given immediately above to calculate the relative areas of heating surface in the different vessels, provided the coefficient of transmission of heat is known in each vessel; if, for the moment, this be taken as the same for each vessel, then if equal differences of temperature are desired from vessel to vessel, this would be obtained by making the heating surfaces in the ratio given above; similarly, if the heating surfaces were made the same in all the vessels the falls in temperature would be in the same ratio.

The transmission of heat is, however, not the same for all the vessels; it decreases from vessel to vessel, due to the greater viscosity and to the incrustations being more pronounced in the later vessels.

Claassen, from actual observations in beet sugar factories, gives the following ratios for the transmission coefficient :—

Vessel.	I.		II.		III.		IV.
Double effect	1	:	0·66		..		..
Triple ,, ...	1	:	0·70	:	0·33		..
Quadruple effect	1	:	0·91	:	0·75	:	0·55

If these figures be taken as data, then to obtain the same temperature difference, the heating surfaces would be in the ratio : —

Double effect—

$$1 : \frac{1·045}{0·66} = 1 : 1·58$$

Triple effect—

$$1 : \frac{1·0075}{0·70} : \frac{1·138}{0·33} = 1 : 1·44 : 3·445$$

Quadruple effect—

$$1 : \frac{1·0055}{0·91} : \frac{1·109}{0·75} : \frac{1·196}{0·55} = 1 : 1·105 : 1·48 : 2·175$$

Now since it is only by larger differences in temperature that viscid juices are brought into violent ebullition, and since it is of great importance to maintain a rapid movement and good circulation, it is better, says Hausbrand, *to have a large fall in temperature between the two last bodies, and not to aim at equalizing the fall in temperature by increasing the heating surface in the later bodies.*

It was, and still is, a very general rule for makers to design evaporators with heating surface increasing from vessel to vessel. Hausbrand recommends that at the very most the *heating surface in the last body should be not greater than and perhaps a little smaller than in the first.*

The Efficiency of a Multiple Effect.—A very important factor in dealing with multiple effects is the evaporation per square foot of heating surface, or, in other words, the capacity; the chief factor is the available fall in temperature from vessel to vessel. A numerical example, which is founded on the methods used by Dessin[9], will show how this fall is controlled.

Let the heating steam be at a pressure of 8 lbs. per square inch, corresponding to a temperature of 234° F., and let the pressure in the last body be 2·42 lbs. per square inch, corresponding to a vacuum of 25 inches, and to a temperature of 132° F.

Then the total fall in temperature is $234 - 132 = 102°$ F., and the average fall from vessel to vessel is 34° F. Let the juice under treatment enter at a density of 1·0709 or 18° Brix, and leave at a density of 1·253 or 55° Brix.

Now for convenience of calculation let there be equal evaporation* in each vessel, then the total evaporation per cent. by weight on original juice is

$$\frac{55 - 18}{55} \times 100 = 67\cdot27 \text{ per cent.}$$

of which each vessel evaporates one-third or 22·42 per cent. of the juice.

Then if B. is the degree Brix of juice in the first vessel

$$\frac{B. - 18}{B.} = \cdot2242$$

whence B. $= 23\cdot2$, corresponding to a density of 1·093. Similarly the juice in the second vessel is found to be of density 32·6 Brix or 1·136.

These densities are correct at a temperature of 84° F., and the densities are required at the temperatures prevailing in the vessels which, assuming the fall in temperature equally divided, are 210° F., 180° F., 160° F.; the respective densities at these temperatures are 1·054, 1·106, 1·229.

Now consider the case of a vertical submerged tube apparatus with tubes 4 feet long, and let the level of the liquid be 6 inches above the level of the tube plate; the vapour formed in the tubes must, so as to disengage itself, be at a pressure equal to the pressure in the vapour space increased by the pressure due to the weight of the column of liquid. This increase in pressure varies with the place where the vapour is formed; the maximum height is 4 feet, the minimum 6 inches, the mean is 27 inches.

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* The results obtained by Hausbrand show that this condition can never obtain; this section is introduced to explain certain important principles in the multiple evaporator, and an ideal case is chosen for simplicity; the application of the conclusions is in no wise invalidated.

Then since the vapour at the moment of its formation is at a greater pressure than that already formed, and since the temperature of a boiling liquid is equal to that of the vapour which it gives off, it follows that the mean temperature of the juice in ebullition is greater than that of the vapour in the vapour space.

Again, the juice is emulsioned with the vapour it gives off and this has a tendency to diminish the density of the boiling juice. Now to obtain an idea of the volume of the contained vapour, Dessin recalls the phenomenon observed when an evaporator stops boiling, namely, that the level of the liquid falls. This fall in level, which is 3 inches in extent, Dessin takes as giving the volume of the contained vapour.

Take the case of the third body of a triple, the vacuum being 25 inches, the vessel 6 feet internal diameter, the tubes 4 feet long, 2 inches diameter, and 630 in number. The total volume of the juice is the volume of the tubes + the volume above the tube plate − the volume occupied by the vapour. We have, then, at rest

$$\text{Vol. of the tubes} = 630 \, \pi \left(\tfrac{1}{12} \times \tfrac{1}{12} \times 4\right) \text{ c. ft.} = 55 \cdot 0 \text{ c. ft.}$$
$$\text{Vol. above tube plate} = \pi \times 3 \times 3 \times \tfrac{1}{2} \text{ c. ft.} = 14 \cdot 1$$
$$\overline{69 \cdot 1}$$

During ebullition the total volume is that found above + that occupied by vapour $= \pi \times 3 \times 3 \times \tfrac{1}{4}$ c. ft. $= 7 \cdot 0$ c. ft. The total volume during ebullition is then $76 \cdot 1$ c. ft.

The finally corrected densities of the juices then appear

$$\text{First vessel, } 1 \cdot 054 \times \frac{69 \cdot 1}{76 \cdot 1} = \cdot 957$$

$$\text{Second vessel, } 1 \cdot 106 \times \frac{69 \cdot 1}{76 \cdot 1} = 1 \cdot 004$$

$$\text{Third vessel, } 1 \cdot 229 \times \frac{69 \cdot 1}{76 \cdot 1} = 1 \cdot 116$$

The vapour then in the third vessel will have to raise a column of liquid of mean height 27 inches, and of density $1 \cdot 116$; this is equivalent to $2 \cdot 20$ inches of mercury or $1 \cdot 09$ lbs. per square inch. The vapour itself was taken at a pressure of $2 \cdot 42$ lbs. per square inch, so that the pressure of the vapour at the moment of its formation is $2 \cdot 42 + 1 \cdot 09 = 3 \cdot 51$ lbs. per square inch, corresponding to a temperature of $147°$ F.; that of the vapour was $132°$ F., a difference of $15°$ F.

Similarly for the second body a difference of $7°$ F., and for the first of $4°$ F. are found.

The efficient fall in temperature from body to body is then

$$\frac{234 - 132 - (15 + 7 + 4)}{3} = 26° \text{ F.}$$

or $76 \cdot 5$ per cent. of what would be the case if the height of juice in ebullition was zero.

THE EVAPORATION OF THE JUICE TO SYRUP.

To illustrate of what vital importance it is to have as great as possible a vacuum in the last body, figures are given below for an identical apparatus where the vacuum in the last body is 27 inches corresponding to a temperature of 114° F., and a pressure of 1·43 lbs. per square inch. Taking the vacua in the other two bodies as 4 inches and 17 inches, the efficient fall in temperature is found to be 30·3° F., that is to say the heating surface compared with the apparatus where the vacuum in the last body is only 25 inches, is 30 per cent. more valuable.

In describing the Welner-Jelinek apparatus it was stated that the height of the column of liquid was only 24 inches. A calculation as above for a final 25 inch vacuum gives the efficient fall in temperature as 28° F. – 29° F., and proportionally higher for a 27 inch vacuum. It was with particular reference to this point that the Welner-Jelinek was designed.

In the film evaporators of the Lillie and Yaryan type there is no increase in pressure due to the height of the boiling column of liquid, but whereas in the latter the juice is contained in the tubes and the vapour formed can only escape at the end of a unit, this vapour must, while in the tubes, be under pressure and tend to increase the boiling point to the detriment of the efficiency of the heating surface. In the Lillie design the vapour formed is free to escape in all directions, and the juice falling in a rain or film there is no increase of temperature in the body of the liquid for the reasons detailed above, and the efficiency of the heating surface must approach the maximum value.

In a quadruple effect submerged vertical tube apparatus the efficient fall in temperature from vessel to vessel on the lines given above works out with a 25 inch vacuum at about 14° F., and with 27 inch vacuum at about 18° F.; for a Welner-Jelinek the corresponding figures are about 16° F. and 20° F. The maximum for the two cases, there being no increase due to head of liquid under treatment, is 25° F. and 30° F. respectively.

In many sugar houses the evaporation is done by triple effects, and it was supposed once that the maximum working number of effects was three, and that with four a sufficient fall in temperature could not be obtained to allow heat to pass from condensed vapour to boiling juice. Formerly vertical apparatus were constructed with tubes even 6 feet long, causing the efficiency of the heating surface to become very low. By reducing the length of the tubes to 3 feet or 3 feet 6 inches, and by attending to the necessity for as low a vacuum as possible in the last body, quadruple effects using back pressure steam only are working in many sugar houses, and do not require high pressure steam at all. In some sugar houses, however, quadruples can be seen where the juice in the first vessel boils under more than atmospheric pressure. With film evaporators quadruple evaporation is general, and quintuple effects have also been constructed. Assuming a minimum fall in temperature for efficient working from vessel to vessel of 20° F., the maximum number of

effects with steam at 234° F., and a final vacuum of 27 inches, will be six, and this result could only be obtained with film evaporators.

It should be noticed that this increase in temperature due to height of liquid is greatest when the pressure is least; in the following table are given figures showing how this varies for different pressures, the density of juice being taken uniformly as unity :—

Mean height of column of liquid causing increase in pressure. Inches.	Vacuum in inches of mercury.					
	5	10	15	20	25	27·5
	Increase in temperature, F°.					
12	1	1	2	2	5	9
18	3·5	4	5	5·5	9	18
24	4	5	6	7	13	22
30	4·5	6	7	9	15·5	25

From the lines immediately above it may be thought that the lower levels of juice in an evaporator will be of higher temperature than the upper; such indeed is not the case, as was shown by Jelinek, whose observations have been extended to the vacuum pan by Curin.[10]

In a well-designed evaporator with a rapid circulation the transfer of heat from the ' *superheated* ' particles at the lower levels is very rapid, so much so as almost altogether to mask the effect of the hydrostatic pressure, so that the objection to long tubes becomes of diminished importance; in apparatus with bad circulation the effect of hydrostatic pressure is very pronounced, and the low duty of many of the evaporators dating back to the eighties may be attributed to these causes. Extreme length of tubes, combined with a high duty, is seen in the Stillman and Kestner apparatus, which utilize the principle of ' *ruissellement* ' or ' *grimpage*,' best rendered in English as ' *creeping*.' This principle can be used in bulk evaporators of conventional design, but the type of labour usually available in the tropics is not to be trusted to use it; hence the writer thinks that a bulk evaporator with tubes of a conservative length with a well-arranged circulation is the best type to adopt.

Conditions are rather different in vacuum pans, and here the effect of the hydrostatic head is very noticeable; that is to say, it is a matter of clinical observation that tall narrow pans are much less rapid boilers than are broader shallower apparatus.

Capacity of Multiples.—A vertical submerged tube triple effect may be considered as giving a high duty when it evaporates 8 lbs. of water per square foot per hour; a quadruple is satisfactory when it evaporates 6; a Lillie quadruple film evaporator will be satisfactory when it gives a duty of 10 lbs., or a triple when it reaches 13 lbs.; a horizontal tube low level apparatus will have a duty lying between these figures, and a ' creeping ' vertical tube apparatus of the ' Stillman ' type will approach or equal in duty the film type.

Increase of the Capacity of a Multiple Effect.—From what has been written it follows that the capacity of a multiple can be increased along the following lines :—

1. By keeping the heating surfaces clean. Evaporators are sometimes constructed with a spare vessel, so that one vessel is always out of use ; the apparatus can then be cleaned without stopping operations.

2. Increase of the fall of temperature, effected either by increasing the pressure of the heating steam or by increasing the vacuum in the last body ; where exhaust steam is used in the first body the increase in pressure is limited by the demands of the motors, and according to Claassen's dictum (*supra*) an increase in the vacuum in the last body over and above 60 cm. or 23·7 inches is not attended with material benefit.

3. Decrease of the height of the liquid contained in the calandria as exemplified in the Welner-Jelinek design.

4. By 'ruissellement,' best obtained in a vertical tube apparatus, by maintaining a low level of juice in the apparatus.

5. By increase in the rapidity of the circulation.

Temperatures in the Multiple.—It has already been shown that the fall in temperature from vessel to vessel, and consequently the temperature in each vessel depends on the heating surface in each vessel, and on the coefficient of transmission of heat in each vessel ; the ratio of heating surfaces to obtain an equal fall of temperature from vessel to vessel as calculated by Hausbrand have already been given ; if, then, as is generally the case, the heating surfaces are equal, the fall of temperature from vessel to vessel will be in inverse proportion to these ratios.

In the triple the total fall will be divided between the three vessels in the ratios :—

$$\text{First vessel} \quad \frac{1}{1 + 1\cdot44 + 3\cdot445} = \cdot1698$$

$$\text{Second vessel} \quad \frac{1\cdot44}{1 + 1\cdot44 + 3\cdot445} = \cdot2445$$

$$\text{Third vessel} \quad \frac{3\cdot445}{1 + 1\cdot44 + 3\cdot445} = \cdot5857$$

If the initial temperature of heating steam be 220° F., and the final temperature be 130° F , the total fall is 90° F., of which there occurs in the

First vessel, $90 \times \cdot1698 = 15\cdot3°$ F.,
Second vessel, $90 \times \cdot2445 = 22\cdot0°$ F.,
Third vessel, $90 \times \cdot5857 = 52\cdot7°$ F.,

and the temperature prevailing will be

First vessel.	Second vessel.	Third vessel.
204·7° F.	182·7° F.	130° F.

A similar calculation for the quadruple gives the total fall as divided in the ratio

$$·1736 \quad : \quad ·1919 \quad : \quad ·2569 \quad : \quad ·3776$$

and if, as before, the total fall is 90° F., there occurs in the

First vessel, $90 \times ·1736 = 15·6°$ F.,
Second vessel, $90 \times ·1919 = 17·3°$ F.,
Third vessel, $90 \times ·2569 = 23·1°$ F.,
Fourth vessel, $90 \times ·3776 = 34·0°$ F.,

and the temperatures prevailing will be

First vessel.	Second vessel.	Third vessel.	Fourth vessel.
204·4° F.	187·1° F.	164° F.	130° F.

Extra Steam.—By this term is meant an arrangement in which steam is taken from an earlier vessel of the evaporator to perform evaporation or heating in some other part of the factory; this scheme is also due to Rillieux and has been developed almost exclusively in the beet sugar industry, where indeed the opportunities for its use are more numerous than in the cane sugar factory, and where, owing to all the fuel being purchased, every economy in this department means a direct source of profit.

To demonstrate the economy of this scheme, let there be 100 parts of juice at 15° Brix, which are to be evaporated to 55° Brix in a triple effect, and finally to 96° Brix at single effect; then there are removed in all $\frac{96-15}{96} \times 100 = 84·37$ parts water, and in the triple alone $\frac{55-15}{55} \times 100 = 72·72$ parts water, so that in the pan there are removed 11·65 parts water; the evaporation in the triple is equivalent to the removal of 24·24 parts water at single effect, so that the total consumption of steam is proportional to $24·24 + 11·65 = 35·89$ parts water per 100 of juice.

Now let the arrangements be changed so that the steam necessary for pan evaporation is taken from the first vessel of the triple; thus evidently both the heating surface of and the evaporators in the first vessel must be increased since this vessel has to supply steam for the second vessel and for the pan. Let the evaporation in either of the last two vessels be a; then in the first vessel the evaporator is $a + ·1165*$; whence it follows that

$$3a + ·1165 = ·7272$$
$$a = ·2036$$

i.e., the first vessel must evaporate $11·65 + 20·36 = 32·01$ parts water per 100 of juice, and of this quantity 20·36 parts go on to the second vessel and 11·65 parts go on to the pan; this quantity is the equivalent evaporation at single effect, where as previously it was 35·89.

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* This assumes equal evaporation in each vessel, a result which does not happen, but the differences do not affect the present reasoning.

Instead of taking steam from the first vessel of an evaporator it may be taken from a later one, and a still greater economy effected; let steam be taken for use in the pan from the second vessel of a triple; thus if a be the evaporation in the last vessel of the triple,

$$3a + \cdot1165 + \cdot1165 = \cdot7272$$
$$\text{whence} \qquad a = \cdot1647$$

that is to say, the evaporation in the first and second vessel is $16\cdot47 + 11\cdot65 = 28\cdot12$, and this quantity is the equivalent evaporation at single effect; other combinations might be the taking of extra steam from both first and second vessels of a triple or quadruple, but as in the second vessel the temperature of the steam is already low, it does not seem there would ever be much opportunity in a cane sugar factory to take steam other than from the first vessel; in a beet sugar factory opportunity arises at the diffusion and carbonation stations.
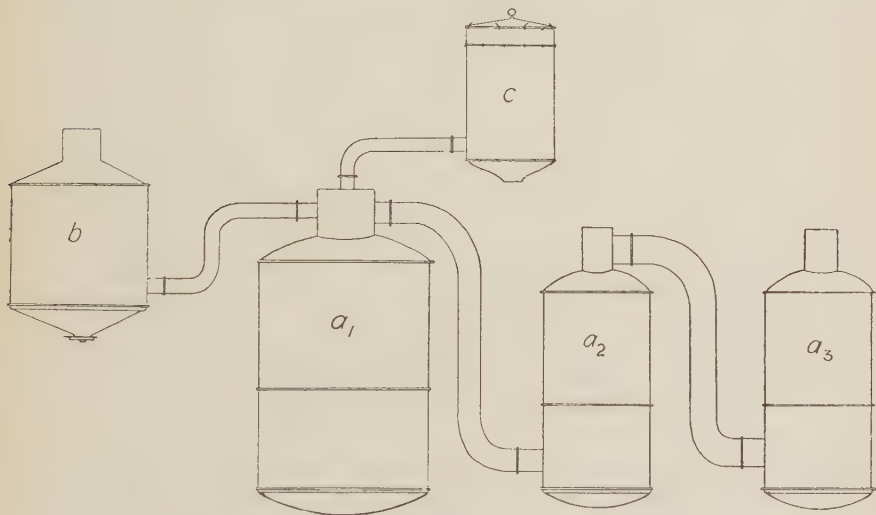
Fig. 178.

This method of evaporation is shown diagrammatically in *Fig. 178*, where $a_1 \, a_2 \, a_3$ is the triple, the first vessel having an enlarged heating surface, so as to provide steam for the pan b and the heater c. Any scheme as the above requires an entire redistribution of the heating surfaces in the evaporative plant. Suppose in a certain factory there is a triple with 2000 square feet heating surface in each vessel and it is desired to alter the arrangements and boil the pan with steam from the first vessel, the output of the factory remaining unaltered; then using the data established above, the heating surface in either the second or third vessel will be $2000 \times \dfrac{20\cdot36}{24\cdot24}$ or 1680 square feet, and in the first vessel it will be $1680 \times \dfrac{32\cdot01}{20\cdot36} = 2140$ square feet.

It is however in the pan that the greatest change is made, for although the amount of work done here is unaltered it is now done with steam, at say, a temperature of 210° F. whereas previously the temperature may have been 260° F; taking an average temperature in the pan of 160° F. the temperature differences are 100° F. and 50° F., so that *at least* double the amount of pan heating surface will be required.

The Pre-evaporator.—The very large heating surfaces required with the use of extra steam have led to the introduction of the Pauly 'pre-evaporator.' This consists of a vessel independent of the evaporator proper and receiving steam at a pressure of about 30 lbs.; the juice is partly concentrated herein and the vapour given off which may be at a pressure of about 15 lbs. per square inch goes to the heaters and pans; the partly concentrated juice passes on to the evaporator which is heated by exhaust steam from the engines; in the pre-evaporator the transmission of heat is high and comparatively small heating surfaces are required. In beet factories it has been established that no appreciable loss of sugar due to the high temperature boiling need obtain. In this scheme there seems great opportunity for the use of the 'Kestner' as a pre-evaporator, as in this type the juices are the minimum time under treatment. This scheme modified by Greiner and known as the Pauly-Greiner is shown in *Fig. 179*; in this arrangement two sets of boilers are used, one, *a*, supplying high pressure steam to the engine *b*, the exhaust from which passes to the first vessel of the evaporator *c*; the other set of boilers *a'* supply steam at 30 lbs. to the pre-evaporator *d* which in turn supplies the pan *e* and heater *f*. Connections are usually established so that the pre-heater and quadruple may, if desired at any time, work as a quintuple.

The relative economy of some of the different possible combinations is calculated and tabulated below; in making these calculations the following data are assumed :—100 parts of juice at 15° Brix, of temperature 82° F., of specific heat ·9, are heated to 212° F.; this juice is evaporated to 55° Brix in the multiple and finally to 96° Brix in the pans; hence 72·72 per cent. of the juice is removed in the multiple and 11·65 per cent. in the pans. The consumption of heat in the heater is 100 × (212 − 82) × ·9 = 11,700 units, and taking the latent heat of steam as 970 this is equivalent to the evaporation at single effect of 12·06 parts of water. At triple effect the evaporation is equivalent to the removal of 24·24 parts water at single effect, so that the number 12·06 + 24·24 + 11·65 = 47·95 is proportional to the heat or steam consumption with this method of working. Now let all the steam required for the pans be taken from the first vessel of the triple; then, as already shown above, 32·01 parts of steam must be there delivered, and the total consumption of heat or steam is proportional to 32·01 + 12·06 or 44·07,
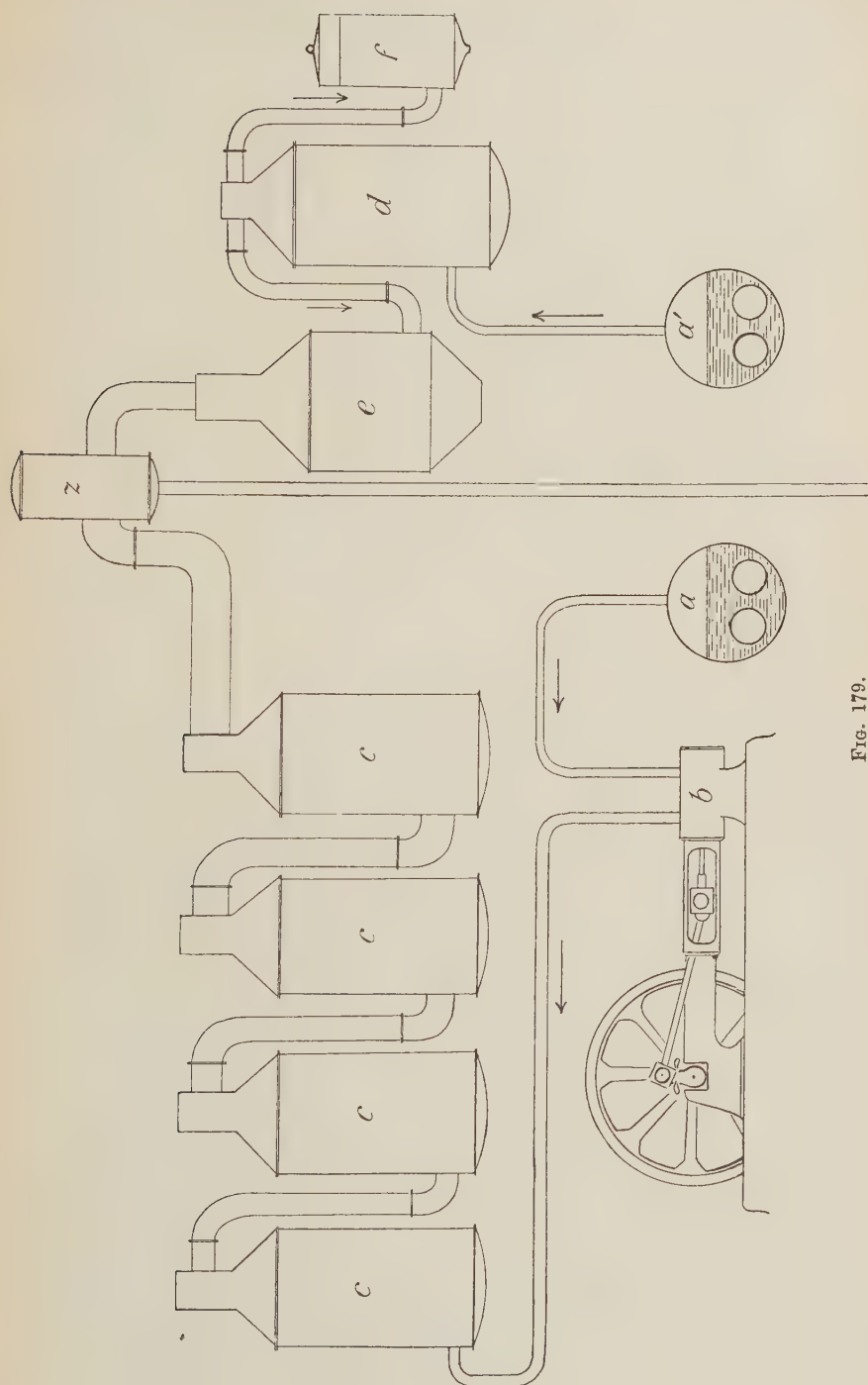
Fig. 179.

i.e., 91 91 per cent. of that required with conventional triple effect evaporation. Results of similar calculations are tabulated below :—

	Relative Consumption of Steam.
Conventional triple evaporation	100·00
Conventional quadruple evaporation	87·28
Triple evaporation and extra steam to pan..	91·91
Pre-evaporator to pan, and triple	91·91
Triple evaporation and extra steam to heater	91·62
Pre-evaporator to heater, and triple	91·62
Triple evaporation and extra steam to pan and heater ..	83·46
Pre-evaporator to pan and heater, and triple..	83·46
Quadruple evaporation and extra steam to pan	81·32
Pre-evaporator to pan, and quadruple	81·32
Quadruple evaporation and extra steam to heater	80·52
Pre-evaporator to heater, and quadruple	80·52
Quadruple evaporation and extra steam to pan and heater..	75·00
Pre-evaporator to pan and heater and quadruple	75·00

In addition combinations of the pre-evaporator with extra steam from the multiple can be devised.

The Picard System.—This method has never, the writer believes, been applied in any sugar factory, although it has been working in other manufacturing processes since 1878. In this scheme part of the vapours given off from the first vessel are drawn off into a compressor and raised to a high pressure; their temperature is thereby increased, and on again being introduced into the calandria of the effect are capable of evaporating a further quantity of water. This scheme can of course be worked to its best advantage where power, as from a fall of water, is available to drive the compressor. This method was described in 1880 by P. O. Whitehead,[11] and its mathematics have been discussed in detail by Svorcik,[12] who as a final result lays down that in a triple with this scheme one part of steam will evaporate altogether 4·248 parts of water. His idea of the regeneration of vapours has been made practical by Selwig and Lange, who have put into practice the scheme of withdrawing part of the vapour from the penultimate vessel of a multiple by the use of live steam injectors, and returning them either to an earlier vessel or utilizing them in heating or in the pans.

Calculation of Heating Surfaces.—When the amount of heat necessary to be transmitted, the difference of temperature between the juice to be heated or juice to be evaporated, and heating steam are known, the requisite surface can be calculated by means of the coefficients of transmission already quoted.

When juices are to be heated the temperature of the juice is taken as the mean of its initial and final temperature; when the juices are to be evaporated the temperature of the juice is taken as the mean temperature of the boiling mass. As an example, let there be 30 metric tons of juice to be heated in one hour from 30° C. to 100° C., with steam at 105° C. The average temperature of the juice to be heated is $30° + \dfrac{100 - 30}{2} = 65°$ C. The difference of temperature is $105° - 65° = 40°$ C. Taking the specific heat of juice as ·9, the heat to be transmitted is $30,000 \times ·9 \times (100 - 30) = 1,890,000$ calories.

The coefficient of transmission for diffusion, &c., juices is 5, *i.e.*, per square metre per minute per 1° C. difference of temperature, 5 calories are transmitted.

Then per hour under the conditions named 1 square metre will transmit $5 \times 40 \times 60 = 12,000$ calories, and the heating surface required is

$$1,890,000 \div 12,000 = 157 \text{ square metres, or 1689 square feet.}$$

Calculations for pans and evaporators may be made on exactly similar lines, using the coefficients of heat transmission given in a preceding section.

Dimensions of Steam and Vapour Piping.—The passage of vapour from the vapour space of one body to the steam drum of the next takes place under a slight difference of pressure; this pressure amounts to 0·3 lb. per square inch, corresponding to a difference in temperature of about 1° F. To calculate from these data the velocity of a gas leaving an orifice requires the use of higher mathematics, which would serve no useful purpose to reproduce here; under the conditions named, the velocity of a gas is of the order 200 feet per second; such a velocity is not obtained in evaporators because of the friction of the gas on the walls of the pipes, abrupt changes in direction, especially those due to baffle plates and save-alls, and also to condensation of a part of the vapour. For steam and vapour pipes it is customary to allow a velocity of 100 feet per second, and for the vapour leaving the last body a velocity of 150 feet per second; if velocities higher than these obtain, a very considerable fall in the temperature of the vapour occurs, reducing the efficiency of the apparatus. As an example of this and other calculations, the case of a triple effect with 4000 square feet heating surface, evaporating 6 lbs. water per square foot per hour, or 2·22 lbs. per second per vessel, is taken.

Steam Pipe.—Taking the temperature of the heating steam to be 234° F., 1 lb. will occupy 17·83 cubic feet, and allowing 1 lb. steam to evaporate 2·90 lbs. water, 2·31 lbs. (= 41·19 cubic feet) will be required per second. At a velocity of 100 feet per second the area of the pipe must be ·4119 square feet, corresponding to a diameter of $8\frac{1}{2}$ inches.

Vapour Pipes.—Taking the temperature of the vapour from the first vessels as 206° F., 1 lb. occupies 29·6 cubic feet; at a velocity of 100 feet per second, the area of the pipe must be ·657 square feet, corresponding to a diameter of 11 inches. The temperature of the vapour from the second vessel being taken as 177° F. will occupy 53·4 cubic feet per lb., and under the same velocity demands a vapour pipe 15 inches in diameter. Finally, for the pipe leading to the condenser, allowing here a velocity of 150 feet per second, a diameter of 21 inches is obtained ; 1 lb. of vapour at 132° F. occupying 152·4 cubic feet.

Injection Water.—Assuming the vacuum in the condenser is 27·5 inches, the corresponding temperature is 104° F., and the temperature of vapour given off in the last body may be taken as 134° F. At this temperature the latent heat of steam is 1022 B.T.U., so that in condensing 1 lb. of vapour at 134° F. and cooling to 104° F. (corresponding to a vacuum of 27·5 inches) 1052 B.T.U. are absorbed. Allowing the injection water to be of temperature 84° F., each pound of water absorbs 20 B.T.U., so that 52·6 lbs. water per pound of vapour will be required, and to obtain this result at least 10 per cent. or 20 per cent. more water must be admitted.

It is, however, only in exceptional cases that so large an amount of injection water is admitted, and the temperature of the discharge is more frequently 115° F. to 120° F. If the temperature of injection water be again taken as 84° F., to obtain discharge water at this temperature, the quantity of injection water required is only thirty times as much as the vapour to be condensed, and this is the quantity usually allowed for in design. The objection to admitting the larger quantities is the accompanying increase in size of the pump, but the economy is only effected at the expense of the vacuum in the last body, and consequently of the efficiency of the heating surface as a whole.

The size of the injection pipe to deliver a definite quantity of water depends on the head, the length, and diameter of the pipe, and the number of bends. The theory of the flow of water in pipes is too complex to be reproduced here, but a table is given below showing the velocity of water at exit from pipes of diameter 4 inches to 12 inches, for lengths of from 40 feet to 100 feet, and with one, two, or three right angle bends. The table has been calculated from the latest formulae ; a constant head of 16 feet has been assumed corresponding to a 25 inch vacuum, and a height of 12 feet of entry of injection water above level in well.

Table giving Velocity of Water at Exit under a Head of 16 feet for different Conditions of Pipe.

No. of Bends.	Length of Pipe. Feet.	DIAMETER OF PIPE. INCHES.								
		4	5	6	7	8	9	10	11	12
		VELOCITY OF FLOW AT EXIT: FEET PER SECOND.								
1	40	13·9	15·0	15·8	16·3	16·9	17·3	17·6	17·9	18·1
2	40	13·7	14·7	15·5	16·0	16·5	16·9	17·3	17·5	17·6
3	40	13·5	14·5	15·2	15·7	16·2	16·5	16·7	17·1	17·3
1	60	12·3	13·4	14·4	14·9	15·7	16·0	16·4	16·7	16·9
2	60	12·1	13·2	14·0	14·6	15·4	15·7	16·0	16·3	16·5
3	60	12·0	13·0	13·8	14·3	15·1	15·4	15·7	16·0	16·3
1	80	11·2	12·2	13·1	13·7	14·4	15·0	15·4	15·7	16·0
2	80	11·0	12·1	12·9	13·5	14·1	14·7	15·1	15·4	15·7
3	80	10·9	11·9	12·8	13·4	14·0	14·3	14·7	15·1	15·4
1	100	10·2	10·6	11·5	12·1	12·9	13·4	13·7	13·9	14·4
2	100	10·1	10·5	11·4	12·0	12·8	13·1	13·5	13·7	14·2
3	100	10·0	10·4	11·3	11·9	12·7	12·9	13·4	13·6	14·1

The calculation of the volume of gases removed by the pump is so unsatisfactory as not to repay study. A certain quantity of air enters the apparatus dissolved in the juice, which is released on boiling, and the juice itself in treatment forms a certain amount of gas ; air, too, will leak into the apparatus, and some will be introduced dissolved in the injection water. Experimental data are so incomplete on these points that they can give little or no help to practice.

Loss of Heat in Evaporators.—In a naked quadruple standard evaporator let the temperatures in the vessels be

°F.

I.	II.	III.	IV.
212	203	187	140

With external air at 82° F.

the excess temperature is 130   121   105   58

Interpolating from the table given in Chapter XIX. the heat losses per square foot per hour are

B.T.U.

I.	II.	III.	IV.
336	308	252	126

Let the area of shell and vapour pipes be ·2 of the total heating surface, then each vessel exposes an area ·05 of the total heating surface, and the losses per hour per square foot of heating surface are

I.	II.	III.	IV.
17	16	13	6

Per square foot of heating surface per hour a quadruple will receive normally 1600 B.T.U.; the first vessel then utilizes 1600 — 17 = 1583 B.T.U.; the second vessel receives 1583 B.T.U., and utilizes 1583 — 16 = 1567 B.T.U.; similarly the third and fourth vessels utilize 1554 B.T.U. and 1548 B.T.U.

The useful effect then is 6252 B.T.U. and not 6400 B.T.U.; that is to say, when in a non-radiating non-conducting quadruple a pound of steam will evaporate four pounds of water, in a naked wrought-iron quadruple it will evaporate 3·906 pounds; this loss will however be recoverable at quadruple effect, so that for every four pounds of water evaporated ·023 lb. steam, or say 22 B.T.U. are to be made up; in a factory evaporating 60,000 lbs. water per hour the B.T.U. to be made up will then be 330,000. In Chapter XIX. a pound of megass is estimated as affording for factory purpose 2922 B.T.U., so that the loss per hour in radiation from a 10,000 square foot naked standard evaporator is of the order 113 lbs. of megass or 2712 lbs. per day.

It is not unusual to see evaporators only protected in part; what is the actual loss is almost impossible to say; this calculation shows, however, that the loss is quite appreciable and well worth saving.

Utilization of Vapours from the last Body.—A not negligible economy of heat may be obtained by using the vapours from the last body to heat cold juices; the temperature to which the juice can be heated depends, of course, on the

Fig. 180.

degree of vacuum in the last body; a 25 inch vacuum corresponds to a temperature 133° F., and with that vacuum this is the highest temperature to which the juice can be raised. A numerical example will make the economy of this scheme clear.

Let there be evaporated under a 25 inch vacuum in the last body of a multiple effect 233 lbs. water per 1000 lbs. of juice; the condensation of this quantity of vapour will afford 238,126 B.T.U. Now, taking the specific heat of juice as 0·9 and the initial temperature as 84° F., to raise 1000 lbs. from 84° F. to 133° F. requires 44,100 B.T.U., so that 18·5 per cent. of the vapour
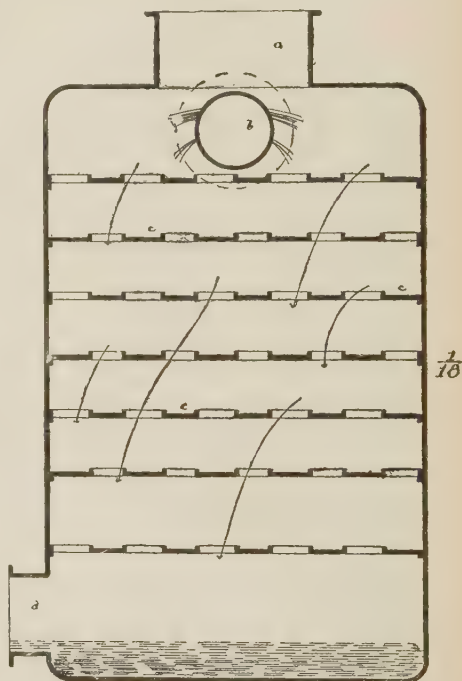
can be condensed by the juice. The megass corresponding to 1000 lbs. of juice will roughly afford 1,000,000 B.T.U., so that the saving calculated on the megass available for fuel will be between 4 and 5 per cent.

If this scheme is used it must be remembered that the juice is at atmospheric pressure and the heating vapour under a high vacuum; unless the the apparatus is carefully constructed and maintained in good order there is then danger of juice being carried away into the condenser.

Condensers.—The condensers which find use in forming and maintaining the vacuum in the last body of an effect may be classed as *jet* or *surface* condensers, or again as *dry* or *wet* condensers. Surface condensers are only used where the vapour from the last body is used to heat juices, as explained immediately above.

The injection condenser, usually employed to condense the vapours given off from the last body of an effect, consists essentially of a cast-iron cylindrical body connected by a pipe, called the vapour pipe, to the vapour space of the effect, and also by a second pipe to the suction of an air pump; a third pipe called the injection pipe leads water from a well to the condenser. A vacuum being formed in the condenser by means of the pump, water enters the condenser under the influence of atmospheric pressure. The vapour given off from the effect meeting the stream of cold water is condensed, and the vacuum maintained; the condenser water and incondensible gases pass to the pump and are there discharged.
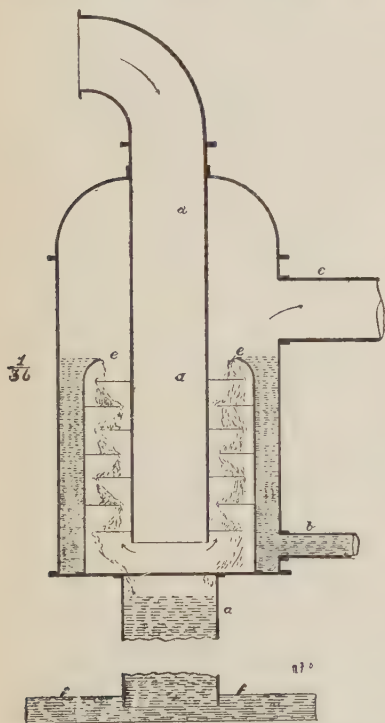
FIG. 181.

As the efficiency of a multiple effect depends very largely on the vacuum in the last body, and this in turn on the completeness of the condensation, attention to the design of the condenser is important. The commonest method of distributing the injection water within the condenser is by means of a rose; with this arrangement there is liability of the holes becoming choked, especially when any but the cleanest water is available. Better arrangements are shown in *Figs. 180* and *181*. In the form shown in *Fig. 180* the vapour enters at *a* and the injection water at *b;* the whole then follows the path indicated by the arrows through the apertures in the plates, and is discharged at *d* to the air pump. In the form shown in *Fig. 181* the injection water

enters at b, overflows over a series of rings and discs in a fine shower, meeting the vapour which moves in the opposite direction forming what is known as a counter-current condenser; as shown this form is applied to what is termed the *dry vacuum*. The method of this form will be readily understood on referring to *Fig. 181*; a is a pipe more than 33 ft. high with its lower end immersed in a tank of water; the atmospheric pressure will support a column of water 33 ft. high, and above this will be a vacuum. Into the condenser water is pumped through the pipe b; this water overflowing at e meets the vapour from the effect conducted through the pipe d. The steam is condensed, and, together with the injection water, discharges itself on to the surface of the column a, and is eventually discharged into the tank f. The incondensible gases are drawn off by an air pump through c.

A large number of patterns of condensers are made, the distribution of the cooling water being very frequently obtained by devices similar to that shown in *Fig. 181*, the arrangement of the rings and discs being capable of great variety.
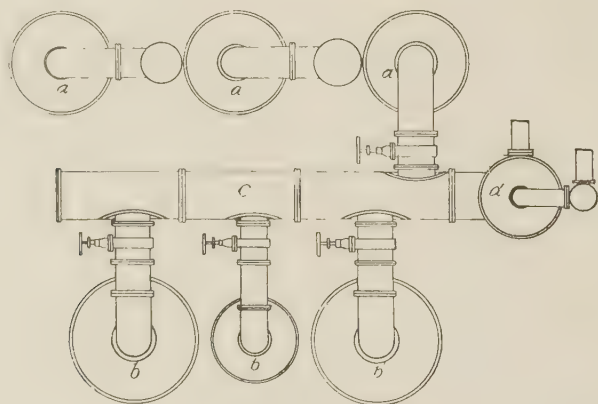
Fig. 182.

Each of these systems has its advantages; a more complete vacuum can be obtained with the dry air pump, but in general two pumps are required; in certain cases where a natural head of water exists the lifting pump may be dispensed with. In the wet system with large plants the size of the pump becomes very inconvenient.

It is impossible to calculate from first principles what should be the size of condensers; Jelinek recommends that they should be not less than 1·5, and Horsin-Déon from 2·5 to 3 times the volume of the pump.

Central Condensation.—Instead of each unit having its own condenser and pump, it is now often the practice to instal one central condenser and pump. A very great economy in steam, piping, oil, repairs, and attendance is thus obtained. In such a case a dry vacuum pump should be used, as a wet pump would have to be of exaggerated dimensions in a factory

of any size. In *Fig. 182* is shown in plan a convenient method of arranging the evaporators and pans for use with a central condenser; the triple is shown at *a*, the pans at *b*, both leading to the vapour main *c* connected to the central condenser *d*.

Vacuum Pumps.—The pumps used in sugar factories to create and to maintain the vacuum fall into two main classes—dry and wet vacuum pumps. In the former type the incondensible gases and the water used in condensation are removed separately, and in the latter class together.

In *Fig. 183* is given a sectional view of a vertical pump. At *a* is the piston or bucket, at *b* the foot or suction valves, and at *c* the discharge valves. These pumps are usually worked in pairs off a beam engine, and are not to be found in recent factories; in older factories as many as six or eight pumps may be worked off one beam, a method which, while economizing steam and labour, runs the risk of stopping the whole factory in case of a small mishap.
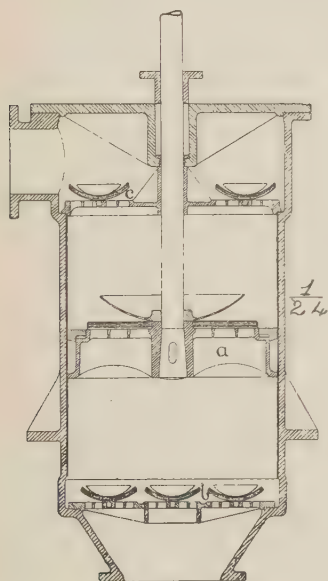
In *Fig. 184* is shown a horizontal torpedo plunger pump, of which many have been and are being used in recent factories. The plunger *e* moving from right to left, the valve *a'* opens and water enters and fills the space behind the plunger; at the same time the water in front of the plunger is discharged through the valve *b*; the valves *a* and *b* being closed, the water is discharged through *d* into the main factory sewer. The valves shown at *b* and *b'* are india rubber disc valves resting on a perforated iron or brass grill; those shown at *a* and *a'* are clack valves working on a hinge; in modern works it is the former type of valves that is employed. Pumps of this type cannot be worked efficiently at a greater speed than 40 revolutions per minute, as it is important that the air drawn in be expelled as completely as possible; this only occurs when the air is allowed to pass through the water, then expelled, followed by the water. If the pump works at a high speed, the water is agitated, air cannot pass through, and more air is left in the barrel than would be the case at a lower speed.

Fig. 183.

The above-described pump is the type usually provided by European engineering firms; where factories have been erected under the influence of United States engineers, wet vacuum pumps of or derived from the
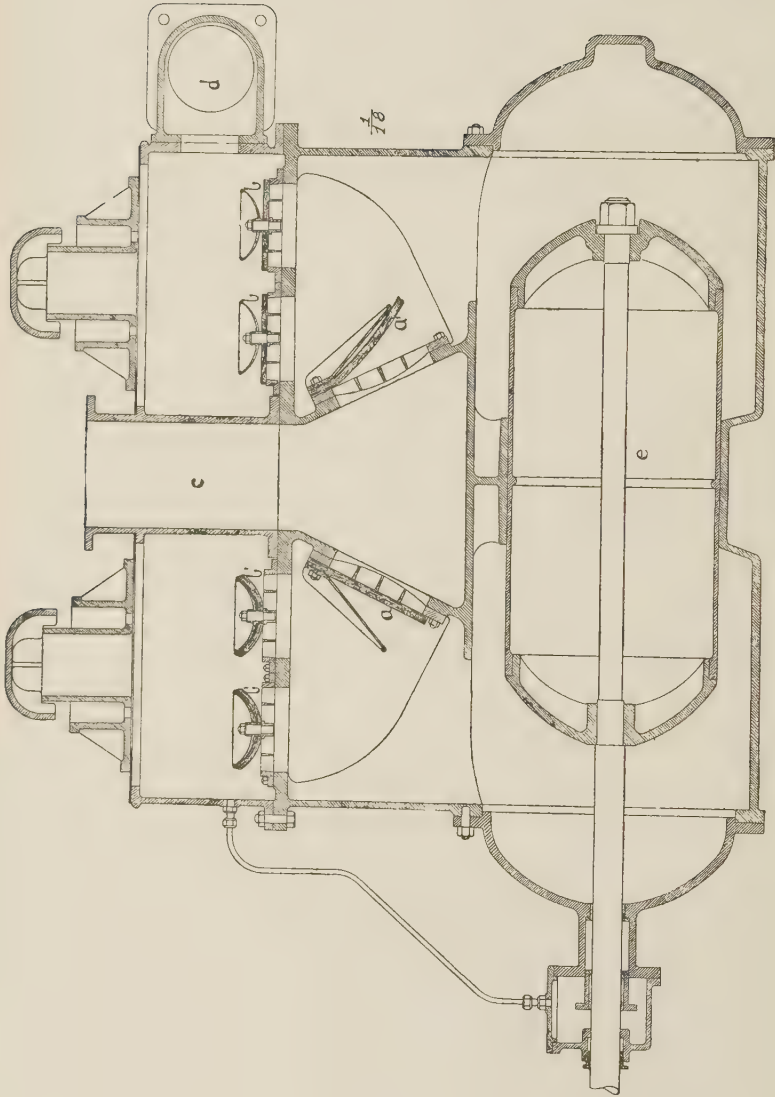
Fig. 184.

Worthington type are often used; a section through such a pump is shown in *Fig. 185*.

A wet vacuum pump that has been extensively installed is the Edwards' patent pump, which allows the air to pass naturally through the water, instead of being churned up with it, as always happens to some extent in the ordinary type. This pump is shown in vertical section in *Fig. 186*. Water from the condenser flows by way of *d* to the reservoir *c;* the conical bucket *b* on the down stroke forces the water into the barrel of the pump; as soon as the bucket rises the entry of water by way of *d* is closed until the bucket has passed, and the water which has been projected into the barrel is lifted and discharged through the valves at *a*, passing away at *e;* at *g* is a relief valve. The incondensible gases are free to escape to the space above the water. These pumps are made double or treble barrelled, so that their action is practically continuous.
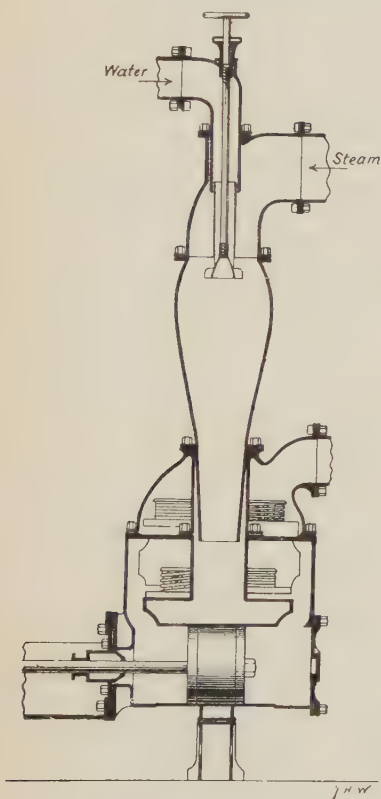
Pumps used to remove the incondensible gases in connection with the dry vacuum are generally of the slide valve pattern; in the earlier pumps at each stroke a certain amount of air was left in the barrel of the pump, to the detriment of the efficiency. To overcome this pumps are fitted with an arrangement whereby at the end of the stroke, communication is made between the two faces of the piston, and the compressed air in front of the piston escapes into the exhausted space behind. There are many excellent designs obtaining this 'equalization of pressure,' that due to the firm of Wegelin & Hübner

FIG. 185.

being shown in *Fig. 187*. There are three valves, *a*, *b*, and *c*, known as the distributing, equalizing, and delivery valves; the valve *a* is designed to allow the air to enter or depart and to connect the suction or discharge to the pan or atmosphere; the delivery valve *c* on the valve *a* is for the escape of air and to prevent air returning to the pump; the equalizing valve *b* is for the purpose of connecting the channels *d* when the piston is at the end of the stroke   When the piston is at the end of a stroke the valve *a* is nearly central and the discharge and suction ports are closed; at this moment the equalizing valve *b* makes connection between the two faces of the piston by means of the

channel d and equalizes the pressure on both sides of the piston; the valve b now closes and a opens, and as the piston moves from right to left air is drawn into the vacuum; the equalizing valve b remains closed and the suction and delivery ports open; at the end of the stroke the valve a is again nearly central and the process described above repeats itself.

The Blancke air pump is of recent introduction and uses flap valves; it is shown in *Fig. 188*.   The motion of the cylinder is from left to right, so that gases are being aspirated in on the left hand side and discharged on the right
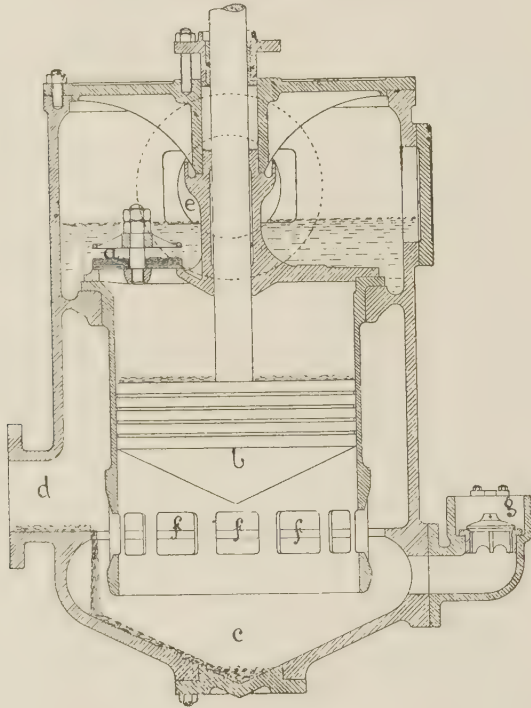
FIG. 186.

hand side.   The suction valve is composed of a series of sleeves, with rectangular openings, A and B, and a ring and flap valve C telescoping together and forming the annular spaces C and D.   E is a spring, helping to close the valve under a slight difference of pressure.   On the compression side of the pump all of the sleeves of the valve are forced together, and the annular spaces C′ and D′ and the openings A′ and B′ are all closed; the compressed air escapes by e', f' and g'; on the aspirating side these openings are closed by the spring H.   The discharge valves are arranged on the lower side of the pump so as to facilitate the removal of water.

Size of Pumps.—Although it is impossible to calculate on first principles the necessary sizes of pumps to maintain a vacuum, certain principles can be developed: the treatment here adopted is mainly after Hausbrand.
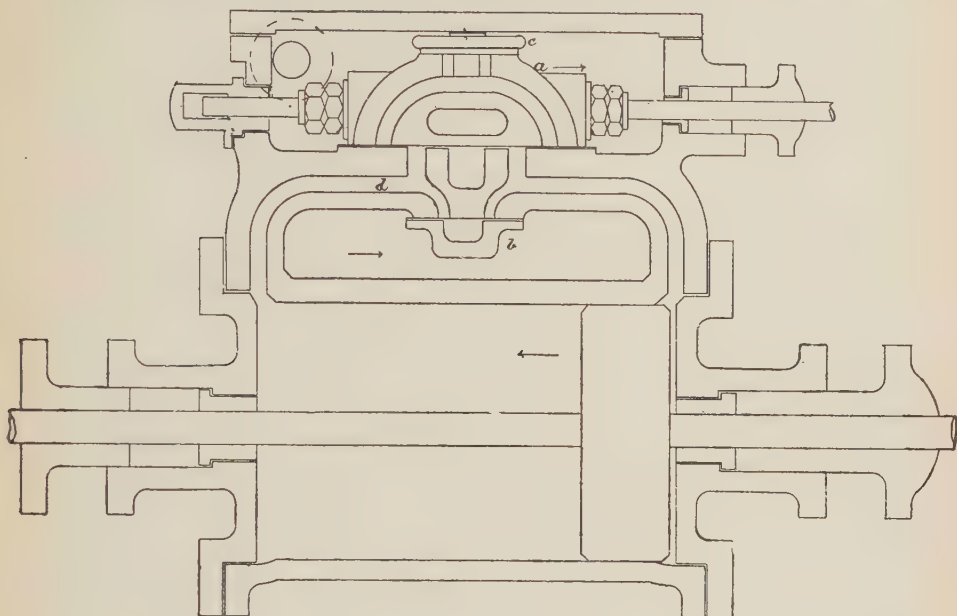
Fig. 187.

The pressure in a condenser is made up of two parts: *a.* the pressure due to the water vapour which depends only on the temperature of the water; *b.* that due to the incondensible gases (referred to below as Air). Thus, with a
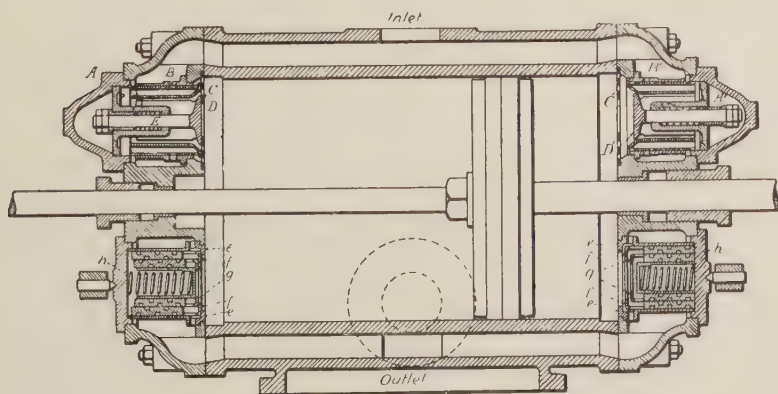
Fig. 188.

vacuum of 24 inches, the pressure is 2·92 lbs. per square inch. Let the temperature of the water in the condenser be 100° F.; the pressure of water vapour at this temperature is ·95 lbs. per square inch; hence the gases are at a

pressure of 1·97 lbs. per square inch. As the temperature of the water increases so does its vapour pressure, and consequently the gases are at a lower pressure. The volume occupied by air or any gas is inversely proportional to the pressure; hence the colder the condenser the less is the specific volume of the gases. As illustrative of the variation in gas pressure in a condenser, there is given below the pressure of the gases where the vacuum is 24 inches or 2·92 lbs. per square inch, and where the temperatures are as shown.

Temperature F°	Pressure of gases. Lbs. per sq. in.	Temperature F°	Pressure of gases. Lbs. per sq. in.
80	2·41	120	1·25
90	2·22	130	·70
100	1·97	140	·04
110	1·65		

Hence when the temperature is 140° F. the gases will occupy sixty times as great a specific volume as when the temperature is 80° F. Gases in condensers arrive from the water used in cooling, from decompositions in the process of boiling the juice, and from leaks in the apparatus. For the moment only the first source will be considered. The gases dissolved from air by water, following on the determinations of Roscoe and Lunt and of Winkler may be thus expressed.

Temperature F°	Lbs. Gases Dissolved per 1000 Lbs. of Water*
60	·0266
70	·0241
80	·0217
90	·0195

The amount of water used to obtain the condensation of the vapour is given by the expression $w = \dfrac{h - t_2 - 32}{t_2 - t_1}$, where w is the water used per unit weight of vapour, h is the total heat of the vapour, t_1 and t_2 are the initial and final temperatures of the cooling water.

For a 24-inch vacuum with cooling water at 60° F., the weights of water required to obtain different temperatures in the condenser, and hence in the discharge water, are as shown in the table below, which also includes the pounds of gases from the water.

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* The gases dissolved by water from air are very nearly in the proportion of two volumes of nitrogen to one of oxygen; it is here assumed that air itself is dissolved; the calculation is barely appreciably affected and the conclusion not at all.

Temperature of Discharge Water. F°	Weight of Water per Pound of Vapour Condensed.	Pounds of Gases from Water.
80	50·4	·001365
90	33·3	·000902
100	24·7	·000669
110	19·6	·000531
120	16·1	·000436
130	13·7	·000371
140	11·8	·000320

The volume of 1 lb. of air in cubic feet is given by the expression

$$\frac{\cdot 3697 \ (459 \cdot 4 + t)}{p}$$

where t is the temperature in Fahrenheit degrees, and p is the pressure in pounds per square inch. In the table below are given for a vacuum of 24 inches, for cooling water at 60° F., and for discharge water at the indicated temperatures, the cubic feet of water, the cubic feet of gases, and the combined volume of cooling water, condensed steam and gases, per pound of steam condensed :—

Temperature of the Discharge Water	Cubic Feet of Cooling Water.	Cubic Feet of Gases.	Cubic Feet of Gases and Water.
80	·8192	·1129	·9321
90	·5888	·0825	·6713
100	·4112	·0703	·4815
110	·2996	·0683	·3649
120	·2736	·0747	·3483
130	·2554	·1155	·3709
140	·2049	1·7712	1·9761

On examining these figures it will be observed that the volume of the gases at first decreases with decreasing quantities of water, reaches a minimum and then rapidly increases; *hence if the gases present in a condenser are proportional to the amount of cooling water admitted, there is a definite temperature in the waste water at which the volume of air is least;* this temperature in the waste water is then the OPTIMUM for the particular condition, and it controls the proper amount of cooling water to be admitted. It is, however, quite impossible to calculate for actual use where this optimum temperature lies, since the amount of air entering the condenser is quite unknown ; in a *tight* apparatus, and if the juice gives off no gas, and if the heating steam is air free, then it could be calculated with reasonable accuracy. As the matter stands, however, all that can be said is that such an optimum condition exists and that it can probably be found by trial and error for each apparatus.

If a series of calculations be made for different vacua in order to obtain the optimum temperature of discharge *on the supposition that the gases introduced are proportional to the amount of water*, it will be found that as the water increases in temperature so does the quantity required. The calculation leads to the following very rough approximation : With initial temperatures of 60°, 70°, 80°, 90° F., the water admitted should be about 10, 25, 35, and 50 times the amount of steam to be condensed.

If calculations on the principles assumed above be made, it will be found for vacua of 24, 25, 26, 27 inches that the volume of gases is very roughly as 6, 9, 15, and 25 ; *i.e.*, on this supposition a pump to produce a 27-inch vacuum must be $\frac{25}{6}$ times as large as one to produce a 24 inch vacuum. If, however, a quantity of air, x, enters the condenser which is independent of the quantity of water admitted, then the sizes of the pump capacity will be as $25 + x : 6 + x$, and as x is positive the ratio of pump capacity will be less than calculated above ; if, however, x is small, as should be the case in a well-built evaporator, a ratio similar to that calculated will be found.

The dry air pump has only to remove the air in the water passing down the barometric column. Since the air is last of all in contact with freshly entering cooling water, it will approximate in temperature to the cooling water. Also since a counter current system of cooling is used, less quantities of water are required. If a series of calculations be made on the lines developed above, comparing the volume of air for the most favourable conditions with wet and dry condensation, it will be found that on an average the volume of air with dry condensation is one-third that obtained with wet condensation. This comparison shows how small need be a dry vacuum pump compared with a wet vacuum pump ; in addition the efficiency and speed of an air pump is much greater than that of a water and air pump.

Empirical rules are very dangerous tools, and when the very variant conditions described above are remembered, it will be at once seen how foolish it is to attempt to give any hard and fast rule connecting size of pump and capacity of evaporator, since this will vary—

(*a*) With temperature of cooling water.

(*b*) With the efficiency of the apparatus as regards air leaks.

(*c*) With the amount of air in the heating steam which finds its way eventually to the condenser.

(*d*) With the vacuum considered desirable.

Of the empirical relations the following may be mentioned :—

In marine engineering practice the pump displacement is five times the volume of water to be removed. This would be a very low capacity for sugar house evaporators.

Jelinek estimated that the pump should displace ·3 cubic metre per kilo. of vapour; this equals 4·8 cubic feet per lb. of vapour, and as it applies to European conditions with cold cooling water would be on the low side for tropical conditions.

Horsin Déon estimates that the wet air pump should displace twelve times the volume of water to be discharged. These rules will be found to give capacities larger than are often observed in practice.

With dry vacuum it has been found that a much smaller cylinder capacity than that required for a wet air pump is necessary, and as an empirical rule it may be stated that the displacement of the dry air pump need be only one-third that necessary for a wet air pump.

Cooling Towers.—In districts where water is scarce it is necessary to use over and over again the condenser water, which has thus to be cooled each time after use; cooling is effected by the action of the air applied either in open or closed towers. The open type generally consists of a skeleton framing of angle iron up to 30 feet high with three or four lower stages; on these are placed layers of faggots or brushwood; the water is delivered by a pump to the highest stage and distributed by gutters over the faggots and falling down is collected in a reservoir at the bottom. A second design consists of a series of steps down which the water flows in a cascade.

Alternatively, a brick shaft with a water distributing device inside is employed; in this case a fan is required to force cooling air up the shaft. The United States makers of the Worthington pump employ such a scheme. The distributing device is a sprinkler (of principle identical with that described on page 305); the cooling surface consists of a number of cylindrical tiles placed vertically the water flowing down these both internally and externally.

In a fourth method, injectors of the Korting pattern arranged round the periphery of a pipe throw the warm water upwards in a fine shower.

Under tropical conditions with cooling air at about 80° F., and condenser water at about 140° F., at the very least 1 sq. ft. cooling surface will be required per gallon of water per hour, to be cooled to 100° F. and an excess of this quantity is to be desired.

Scale in Evaporators.— Scale deposited on the tubes of evaporators is due either to suspended matters carried forward in the juice or to the deposit of dissolved bodies due to the concentration of the juice.

The elimination of the first cause can be obtained by a filtration of the juice *en masse*, either through mechanical filters or through sand filters; a useful effect may also be obtained by passing the juice through strainers of very fine mesh. A good filtration of the juice has an enormous effect in the prevention of scale, and accordingly in increasing the efficiency of the apparatus. The interfiltration of the partially concentrated juice on its way from vessel to vessel with the view of removing the matter deposited on concentration has also been employed.

Failing these appliances, the prevention of scale can only be controlled by care in clarification. Excessive scale in evaporators can often be traced to bad clarification and imperfect settling, that is to say, to lack of craft skill on the part of the responsible workman; too little lime often results in a badly settling juice.

Various mechanical devices have been employed to diminish the deposit of scale. Of these may be mentioned that of Novak,[3] who suspends from the dome of the vessel chains which hang down in the tubes; the chains either depend from springs or are supported in pairs from the end of a suspended pivoted arm; the motion of the liquid keeps the chains moving against the sides of the tubes, and a part of the scale also deposits on the chains themselves.

Lagrell and Chantrelle[3] devised the scheme of placing a hollow rod, of nearly the same specific gravity as that of the liquid in each vessel, inside each tube; along this rod is cut a spiral; the motion of the liquid keeps this rod continually rotating against the side of the tube.

The Lillie apparatus is designed so that the direction of flow can be changed at will, and it is claimed that this change of movement prevents or lessens the deposit of scale.

The chief bodies that occur in the deposit of scale are the silicates, phosphates, and sulphate of lime; the two former seem to be of general occurrence; but a sulphate scale in factories not employing sulphur does not appear to be universal; it does not occur except in small quantities in the analyses quoted below due to Pellet and Geerligs, but occurs in large quantities in some of those due to Peck[13] of Hawaiian scales.

Phosphate of lime does not, according to Geerligs and Tervooren[14], occur in juices in solution, but in a colloid state, and hence does not occur in scales from juices which have been filtered, and they state that the same is also true of silica. Peck[13], however, has found phosphate of lime in a state of true solution, the amount decreasing with the quantity of lime used in clarification.

From the analyses quoted below it will be seen that it is in the earlier vessels that phosphates are deposited, silicates predominating in the later ones.

The 'fats' that occur in scales are due to the cane wax and also, according to Shorey[16], to the decomposition of the lecithins of the cane.

The removal of the scale is only to be obtained by mechanical means with scrapers and wire brushes, preceded by a preliminary treatment with appropriate solvents. Phosphate scales are best treated with hydrochloric acid, and silicate scales with caustic soda, in 1 per cent. solution. Sulphate scales are more troublesome to remove, and are best treated by first boiling with sodium carbonate and then with hydrochloric acid; the action of the sodium carbonate is to convert the sulphate of lime to carbonate, which is then attacked by the acid.

FIG. 18.

ISCAMBINE.

$\frac{3}{4}$
SIZE

PLATE XVII

COMPOSITION OF SCALE IN EVAPORATORS.

	First Body.	Second Body.	Third Body.
Water and Organic Matter ..	29·80	26·70	18·60
Silica	·40	23·40	69·80
Iron and Alumina	3·80	9·98	2·80
Lime..	46·30	25·80	6·80
Magnesia	1·36	·81	1·08
Phosphoric Acid	17·10	11·70	trace
Sulphuric Acid	·00	·00	trace
Copper	trace	trace	trace
Undetermined	1·24	1·61	·92

(PELLET.)

	First Vessel.	Second Vessel.	Third Vessel.	Fourth Vessel.
Phosphate of Lime	57·85	56·98	15·02	7·49
Sulphate of Lime	2·02	1·92	·54	1·65
Carbonate of Lime	3·25	4·68	19·55	9·93
Silicate of Lime..	7·86	13·31	·71	7·02
Oxalate of Lime	....	....	11·32	11·27
Iron Oxide..	2·03	1·53	2·31	2·58
Combustible Matter	20·37	13·41	11·04	5·08
Silica	7·79	7·43	39·26	54·34

(GEERLIGS.)

	First Body.	First Body.	Second Body.	Second Body.	Third Body.	Third Body.	Fourth Body.	Fourth Body.
Silica	5·91	17·08	10·43	·36	6·17	36·31	52·51	24·65
Iron and Alumina.	1·45	2·32	2·18	3·42	·28	·84	3·05	·77
Lime	48·33	44·59	44·94	51·44	44·47	31·87	25·24	61·95
Magnesia	3·79	·75	3·37	2·51	·46	2·94	2·55	1·22
Phosphoric Acid ..	38·62	8·98	32·22	40·00	1·22	25·71	9·43	8·00
Sulphuric Acid ..	1·60	26·60	6·08	1·79	46·02	2·74	6·70	3·44

(PECK.)

Peck's analyses are expressed as percentages on the mineral matter of the scale.

REFERENCES IN CHAPTER XVI.

1. Ware's *Beet Sugar Manufacture*, p. 122.

2. *Zeits. für Zucker. in Böhmen*, 21, 169.

3. Quoted in Ware's *Beet Sugar Manufacture*.

4. *Bull. Assoc.*, 27, 207.

5. *I. S. J.*, 42.

6. *Bull. Assoc.*, **15,** 16.

7. *H. P. M.*, December, 1904.

8. *Evaporating, Condensing, and Cooling Apparatus.*   Hausbrand.

9. *Journal des Fabricants de Sucre.*

10. *Zeits. für Zucker. in Böhmen.*, **25,** 176.

11. *S. C.*, 135, 136.

12. *Zeits. für Zucker. in Böhmen.* **7,** 187.

13. *Bull.* 21, *Agric. H.S.P.A.*

14. *I. S. J.*, 85.

15. *J. A. C. S.*, XX., 113.

CHAPTER XVII.

THE CONCENTRATION OF THE SYRUP TO MASSECUITE.

The juice after being treated in the multiple effect evaporator emerges as a thick syrup of density about 1·25, and contains about 55 per cent. of solids in solution. Before being passed on to the vacuum pan to be boiled to grain it is sometimes subjected to a further treatment. This treatment may be either mechanical or chemical; when high class consumption sugars are being made the syrup is sometimes sulphured or treated with phosphoric acid or other decolourant; this treatment is often combined with a filtration of the syrup in sand filters or in the mechanical filters already described; in other factories the only treatment that the syrup receives is that it is allowed to stand and to deposit its suspended matter; the practice of reheating the syrup in connection with steam economy schemes has been described in Chapter XVI.

In the vacuum pan the syrup is further concentrated until it is a magma of crystals of sugar and mother liquor; the usual routine processes followed are outlined below; the magma of crystals of sugar and mother liquor is known as massecuite.

Processes followed.—In the actual routine work the processes followed to obtain the sugar in the juice are as below.

1. Repeated Boilings.—The syrup is boiled to a masse cuite and the crystals separated from the mother liquor giving first sugar and first molasses; the first molasses are boiled into second massecuite and from this is obtained second sugar and second molasses; this process is carried on until fourth or even fifth sugar is obtained after which the molasses are, or should be, exhausted; the number of operations required to obtain exhausted molasses depends very largely on the initial purity of the juice; the purer the juice the purer being the first molasses and so on. The first massecuite may be cooled before the crystals are separated from the mother liquor or it may be treated direct from the pan; if cooled, it may be cooled at rest or in motion. With juices of purity 85 or over, the first molasses are generally pure enough to boil to grain; other first molasses, and in all cases second and subsequent molasses, are boiled blank, *i.e.*, crystals are not formed in the pan but appear after the mass has been struck out, and allowed to cool for a number of days.

This scheme gives as many as four or even five grades of sugar and is wasteful of time, fuel, and labour; in addition, the third and fourth sugars will often not be treated in the centrifugals for a whole year after they are made, entailing an excessive floor space and the locking up of much money.

2. *Return of Molasses.*—In many factories molasses from first massecuites are worked up with the syrup and are not boiled separately, a mixed strike of syrup and molasses being obtained; from this strike a high grade sugar will be obtained, and often one boiling of the resulting molasses is enough to separate them into crystals and exhausted molasses. A high initial purity in the juice is demanded for the best use of this process, which is most applicable in connection with crystallization in motion schemes.

3. *Return of Low Products.*—The product obtained from massecuites of low purity boiled blank contain generally less than 90 per cent. of sugar, and their sale as such is in general unremunerative; they are usually subjected to a process of refining in the factory either by being melted in the juices or by being used as 'seed' in the pan; when used in the latter way the process of granulating the syrup is dispensed with; the fine grained low sugar is taken into the pan in which there is already a quantity of syrup, and the deposit of sugar from the concentrated syrup in the pan takes place on the crystals already present.

4. *Suppression of Low Products.*—By this term is meant processes where low products are entirely suppressed, not by the clumsy process of re-melting them but by obtaining an exhausted molasses without their appearance; this depends on the carefully controlled return of the molasses combined with cooling in motion, and is discussed subsequently.

Of these processes the last is the most rational one and is described in detail afterwards. It is shown also below that the purer the massecuite the purer are the resulting molasses; the return of low sugars increases the purity of the massecuites and hence of the molasses, while it is the object of the process of manufacture to reduce this as much as possible in each step; in addition continual return of low products keeps sugar in process longer, thus increasing entrainment and other obscure losses and adds to the work of the centrifugals as part of the sugar is cured at least twice.

Standard Type of Vacuum Pan.—The vacuum pan is the name given to the vessel in which the final concentration takes place; the means of obtaining and maintaining the vacuum are precisely similar to those given in the preceding chapter, and the principles detailed there are, *mutatis mutandis*, applicable to the single effect pan. Some points of special interest are, however, discussed later. The vacuum pan was invented early in the nineteenth century by Howard, whose name is also associated with the invention of the filter-press. As made by him the apparatus consisted of a double-bottomed shallow iron pan, steam being admitted to the double-bottom; a partial vacuum was obtained by condensing the vapour given off by a jet of water allowed to gravitate down from an overhead tank; no pump was at first employed.
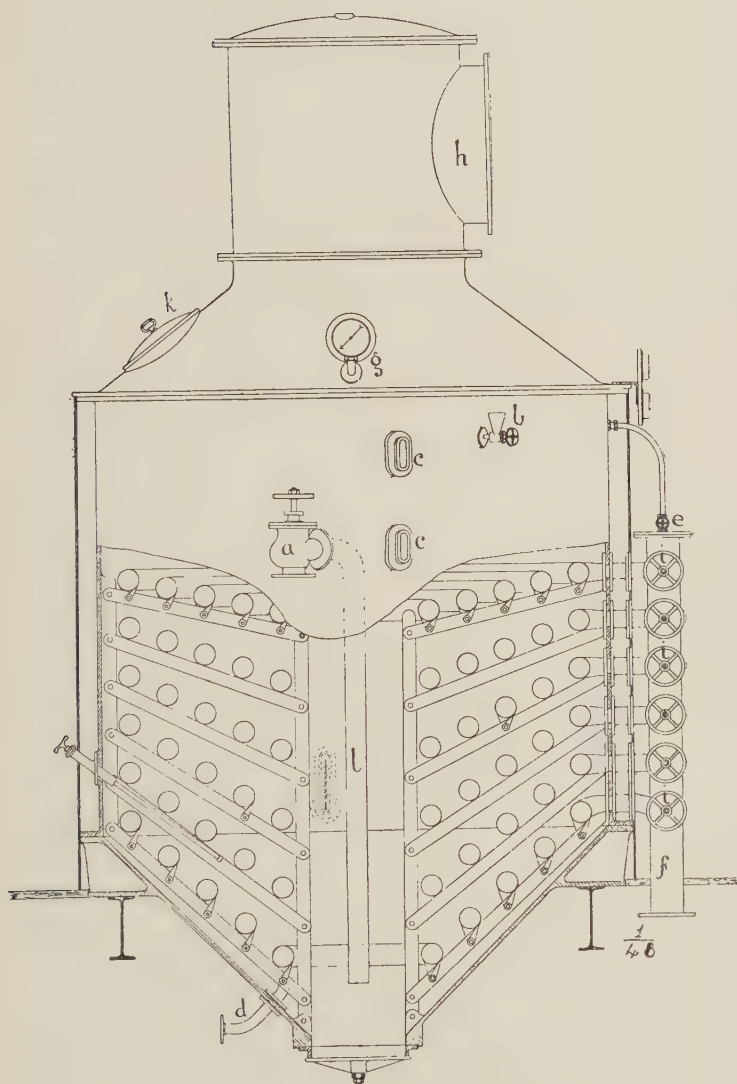
FIG. 189.

The great majority of vacuum pans in use at the present day consist of a vertical cylindrical iron body of approximately equal length and width; this is often called the belt and is covered on the top by a spherical or conical cap called the dome; on the dome is placed the head box whence leads the vapour pipe to the pump; the lower portion of the pan is formed by an inverted cone called the saucer or well; the massecuite is discharged by a door at the centre of the well. In what may be referred to as the Standard type of vacuum pan, the heating surface consists of a number of helical copper coils, reaching from the bottom to a little above the centre of the pan, and so arranged as to divide the heating surface as uniformly as possible. In *Fig. 189* is shown a view partly in section and partly in elevation of a modern pan. The coils are seven in number and are $4\frac{1}{2}$ inches in diameter; they are supported by stay rods fixed to the side of the pan; they each pass through the side of the pan and communicate with the steam pipe f; each coil has its own valve i whereby steam can be admitted to any or all of them; connection is also made to a second pipe (not shown) carrying exhaust steam, so that this can be utilized when available. In modern practice the maximum length of coil used is one about 200 times the diameter; beyond this length it is found that the condensed water does not leave the pipe fast enough to obtain an efficient heating surface. The syrup is brought into the pan by the pipe l controlled by the valve shown at a; this pipe reaches down to the bottom of the pan, so that the lighter syrup enters at the bottom and rising upwards becomes uniformly distributed; each coil is closed by a flange d at its lowest point, which carries a smaller pipe conveying the water of condensation to a steam trap or separator; at e is shown a pipe connected to the main steam whereby steam is introduced to the interior of the pan for the purpose of removing sugar after a strike; at k is a manhole giving access to the pan, at g the vacuum gauge, at c a sight glass, and at b the cock for breaking vacuum; in the pan shown there are approximately 1,000 square feet heating surface, the vessel holding when full 30 tons of massecuite. Special points with regard to this type of pan are that the coils are often made double, alternately right and left handed helices, and that the condensed water is trapped at every fifty feet or so of coil.

Vertical Tube Pan.—A view of this pan is shown in *Fig. 190*, and is often referred to as a calandria pan. The main portion of the heating surface is contained in the vertical tube belt, the tubes of which are generally about four inches in diameter; the coil shown in the lower portion of the pan is for the purpose of graining when only a small quantity of syrup is used for that purpose; it is also necessary so as to distribute the heating surface over the lower portion of the apparatus. Frequently the upper tube plate of the calandria is made sloping slightly downwards at an angle from the circumference towards the centre of the pan with the object of preventing an accumu-
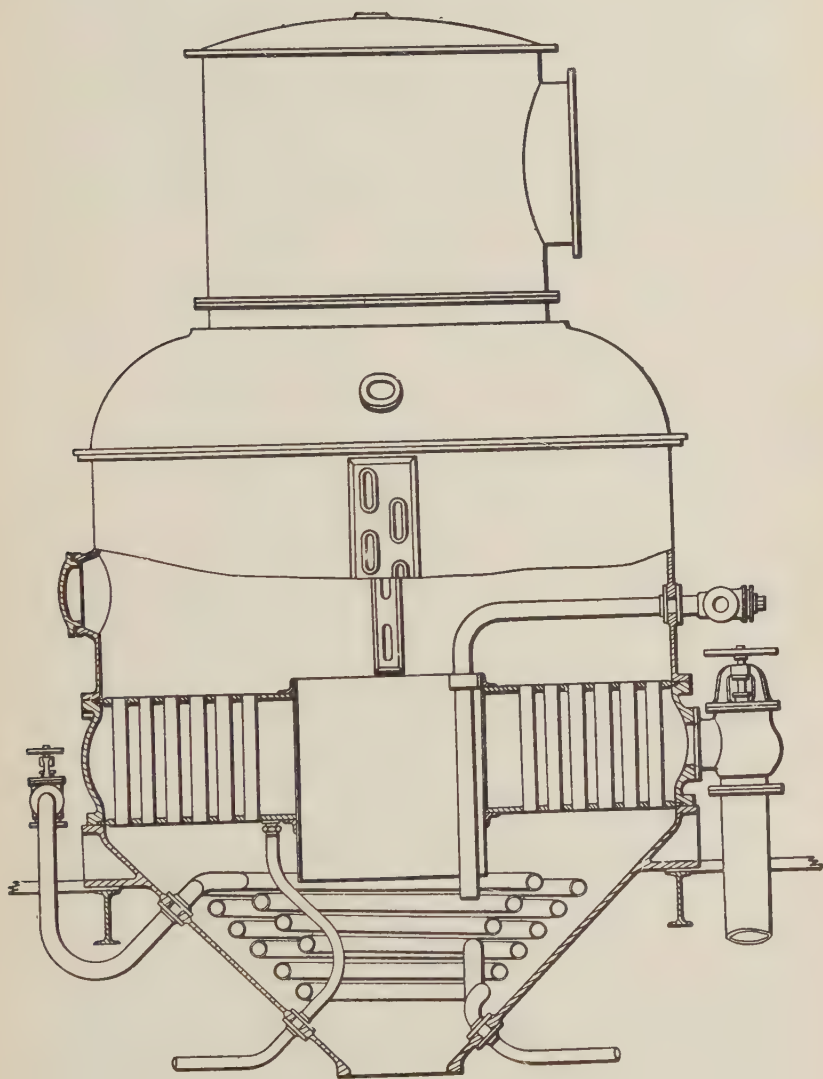
Fig. 190.

lation of massecuite on a level surface. In pans of this type about 30 per cent. more heating surface can be arranged for than in the pans of standard pattern, the gross cubical contents of the pans being the same.

Welner-Jelinek Pan.—The *Welner-Jelinek* single effect pan follows the same general lines as the multiple evaporator; instead, however, of the sides terminating at right angles to the bottom, they are vertical for a part only and afterwards slope in at an angle of 45°, being about two feet distant from each other at the bottom of the pan. The heating surface consists of horizontal tubes, about one inch in diameter and arranged in nests; each tube is distant from the next by about four inches; the nests are placed above each other in stages of from two to four chambers, varying with the size of the pan, and steam can be admitted independently to each stage.
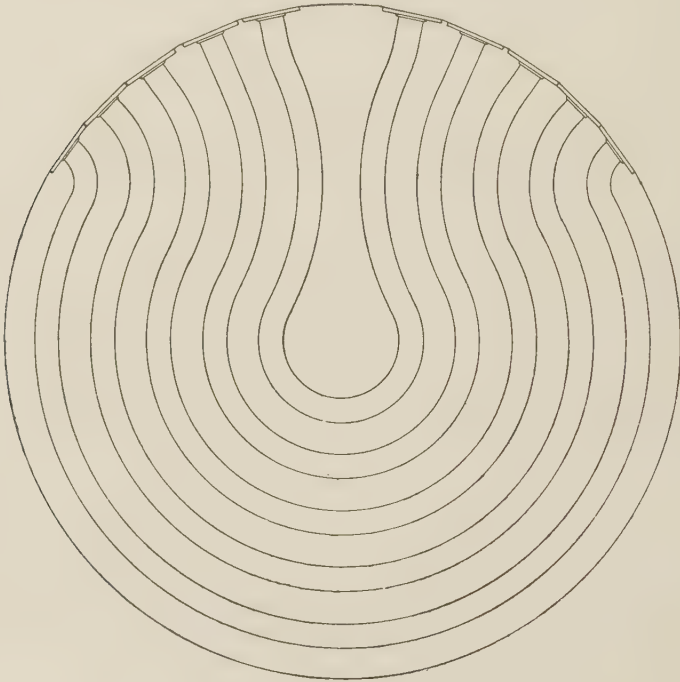
Fig. 191.

Express Vacuum Pan.— The heating surface of this pan is arranged similarly to that figured in the description of this type in Chapter XVI.

Short Coil Pans.—The first vacuum pans constructed held less than five tons of massecuite, and when built on the lines of the 'Standard' type called for coils of only comparatively short length. With increase in size of pans an increase in length of coil followed, and it was soon found that the efficiency of the heating surface fell; this was due to the steam becoming

condensed in the coil long before it reached the tail, so that a large portion was so much dead surface. Several devices have been brought out to remedy this defect, one of which is shown in *Fig. 191;* it is known as the '*lyre coil.*' As many as eight coils form a nest in one plane which is tilted a little from the horizontal so as to facilitate drainage; the ends of the coils pass through
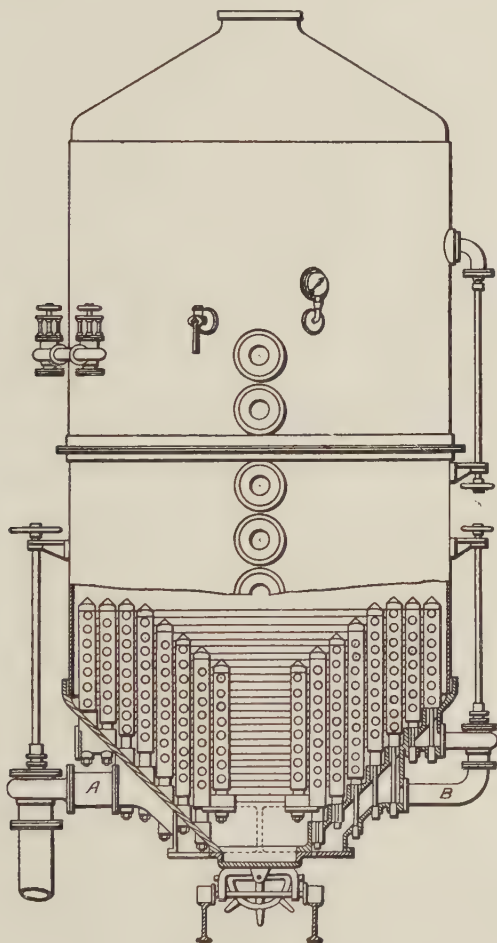
Fig. 192.

the walls of the pan into collector boxes. In a pan of this type containing, say, nine nests, the collector boxes will be divided by horizontal partitions into three compartments, to any of which steam can be admitted or cut off independently.

In these types it is usual to arrange a helical coil within the saucer of the pan.

Greiner Pan.—The pan designed by Greiner was amongst the first departures from the 'Standard' pattern. It was constructed with the idea of obtaining a large heating surface and placing the same all in the lower part of the pan, so that the whole heating surface would be in use from the start of the boiling. As now made it is shown partly in section in *Fig. 192*. The heating surface consists of a number of concentric elements supported on cast-iron standards. Steam is admitted and condensed water taken away at the bottom of each element; the valve *A* controls the admission of steam to the small elements used in the process of obtaining grain, and that at *B* to the larger elements used when the pan is working at its full capacity.

Shape of Pan.—Following on the principles developed in Chapter XVI. it is easy to see that high pans of small diameter will be less efficient than shallower pans, since the height of the column of massecuite will materially increase the boiling temperature of the mass; on the other hand, there are mechanical difficulties in the way of indefinitely increasing the diameter of pans, and with helical coils as heating surface, as shown immediately above, the longer coils required in pans of large diameter tend to become very inefficient; the most efficient shape of pan then becomes one of considerable diameter in proportion to height, with a tubular or short coil system of heating surface.

Technique of Boiling.—The actual process of boiling the pan may be divided into three stages : the granulation, the growing of the crystals, and the bringing up to strike. The granulation is effected by forming in the pan a solution of sugar saturated at a certain temperature, and then by causing the temperature to fall to make the sugar crystallize. Different methods for effecting this exist: the temperature may be lowered by increasing the quantity of injection water and so obtaining a more complete vacuum, by shutting off the supply of steam from the coils, or by introducing a quantity of cold syrup; in whatever way the granulation is obtained the sugar separates as minute, barely visible crystals. In forming grain some pan boilers take in at one charge the whole amount of syrup from which they intend to granulate, and others take in smaller charges gradually working up to the requisite amount. Instead of forming grain from the syrup the practice of *seed grain* is extensively followed; in this process a quantity of a small grained sugar obtained from previous work is taken into the pan, together with the first charge of syrup, and the crystals thus introduced form the points upon which the sugar deposits in the subsequent process; the sugar used is generally the small grained sugar resulting from the after-boilings of molasses. One ton of such sugar can in general be used as grain for every 25 or 30 tons of massecuite that the pan holds. This procedure, besides saving time in boiling the first charge of grain, forms a very economical method of suppressing a portion of the low products. In forming grain the quantity of syrup used for granu-

lation depends on the type of sugar required; when a large crystal is desired only a small quantity of syrup is granulated. This process is known as 'graining low down.' Forming grain from a large quantity of syrup, known as 'graining high up,' will result in a sugar with small crystals. After the granulation has been effected, the next step is to feed the grain with charges of syrup, the object of the operator being to deposit the sugar that now separates on the crystals already formed and not to allow it to form new crystals ('false grain' or 'dust'). To avoid the occurrence of a second crop of crystals the pan must be boiled evenly, there must be no sudden alteration in temperature due to variation in quantity of steam or injection water, or by taking in too large charges of cold syrup which, by locally reducing the temperature in a part of the pan, causes a deposit of a fresh crop of crystals. The scheme of feeding the pan continuously instead of intermittently is dangerous, as, owing to alterations in steam pressure over which the pan boiler has no control, slight variations may result in false grain being formed. Should this occur from any cause pan boilers have two methods for its removal: one is to partly cut off the injection water and so raise the temperature within the pan, the finer crystals dissolving; the second method is to take in a large charge of syrup or even juice which dissolves the finer crystals; this last method is termed by pan boilers 'washing.' When making large grained sugars for direct consumption skilful pan boilers frequently, during the boiling of the strike, take in large charges of syrup for the purpose of dissolving the smaller crystals; this process is called 'opening out' or 'boiling free,' and in skilful hands gives large, fine, bold crystals, but with less skilled operators is liable to cause a serious deposit of false grain. Winter's patent, referred to later, gives another means of removing the smaller crystals.

When the pan is full no more syrup is taken in, but the temperature is gradually raised by cutting off the injection water until the striking point, which can only be determined by experience, is reached; the water content to which a strike can be boiled depends largely on the purity of the juice, but it is also controlled by such influences as the size of the pan outlet, and time available for striking the pan. The greater the purity the less may be the water content, although an impure massecuite with more water than a pure one may still have a greater degree Brix. After a pan has been once filled it is often advisable to strike out only half, and to continue boiling on the remainder; this process is known as 'doubling,' and the discharged massecuite is termed the 'first cut'; the object is to save time and to obtain a large grained sugar in the second and subsequent cuts. This process may, with exceptionally pure juices, be continued four or five times, whilst juices of low purity may not give a single 'double'; in any case there is always a point beyond which the sugar crystal refuses to grow, and any attempt to further increase its size ends in a fresh deposit of minute crystals.

Heating Surface.—Calculations of the heating surface requisite for vacuum pans can be made on the same lines as have already been given when dealing with the designs of multiple effect evaporators; coefficients of the heat transmission for the conditions in the vacuum pan were given there; these calculations are not of much avail as the data are uncertain and of necessity vary with the actual conditions of working. Further, while in the multiple evaporator the whole heating surface is constantly active and the juice level remains constant, in the vacuum pan during part of the process only is the whole of the heating surface in use, and the level of the contents of the pan is constantly changing. This is the more marked the taller the pan is, and consequently the higher the pan is the less is the efficiency of the heating surface; the effect of a high level in the liquid under treatment in decreasing the mean temperature difference between heating steam and heated liquid was explained in Chapter XVI., and a similar cause is at work in the vacuum pan; hence pans that are shallow in proportion to height are found to be ' quick boiling' pans. As an example of an actual case let the maximum height of the massecuite in a pan be 10 feet, so that the average height for the boiling is 5 feet; the average density of the contents of the pan can be only very approximately estimated; the syrup enters at a density of, say, 1·25, and is discharged as massecuite at a density of about 1·50; allowing for the decrease in density due to emulsioning with gases, as was done when dealing with the multiple evaporator, the mean density of the boiling mass is found to be about 1·21; the weight of a column of liquid 5 feet high and of density 1·21, and of 1-inch cross section, is equivalent to a column of mercury 5·34 inches high, or to a pressure of 2·62 lbs. per square inch; if the pressure of the liberated vapour be taken as 2·42 lbs. per square inch corresponding to a vacuum of 25 inches, the mean pressure of the vapour at the moment of its formation is $2·62 + 2·42 = 5·04$ lbs. per square inch, corresponding to a temperature of 162° F., which may be taken as the mean temperature of the boiling mass.

Now the mean pressure of the steam in the coils may be taken as 20 lbs. per square inch, corresponding to a temperature of 259° F. The difference in temperature between the heating steam and the boiling liquid is then 97° F.; for a triple effect dealt with in the previous chapter a mean temperature difference of 24·3° F. was obtained. A modern triple effect evaporator will evaporate 6 lbs. of water per square foot per hour, so that on these grounds a single effect pan should evaporate under the conditions detailed about 24 lbs. As a matter of fact, experience has shown that in the single effect vacuum pan an evaporation of only 12 to 15 lbs. can be reckoned on; the greater density of the material under treatment implying greater viscosity—and consequent greater difficulty—for the disentanglement of vapour, and at the same time decreasing the coefficient of transmission of heat. In addition, whatever be the actual evaporation during working, for a part of the operation the whole

heating surface is not in use. As a rule, modern pans have a capacity of about 70 lbs. of massecuite per square foot of heating surface ; these data are sufficient to calculate the size of pans for the concentration of any given quantity of syrup.

The effect of a low vacuum in the single effect pan is not so noticeable as affecting the temperature difference as in the multiple effect ; if in the example worked above, a 27-inch vacuum be assumed, the mean pressure of the vapour at the moment of its formation is found to be 3·86 lbs. per square inch, corresponding to a temperature of 152° F., and giving a temperature difference of 107° F. as compared with 97° F. or roughly 10 per cent. ; for the triple effect considered in the previous chapter the same final vacua altered the temperature difference to the extent of 30 per cent.
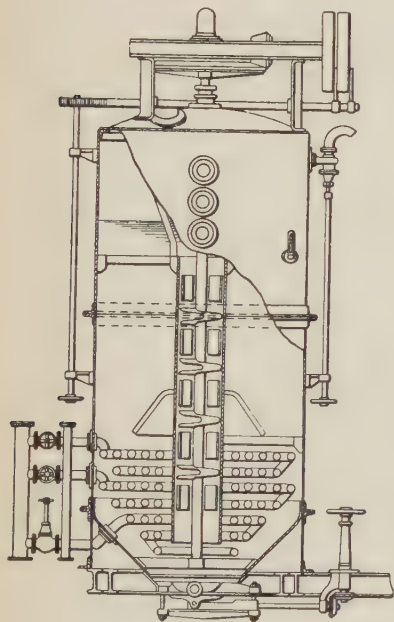
Fig. 193.

Relation of Heating Surface to Capacity.—In a standard type of coil pan there will be per cubic foot of capacity from 1·2 to 1·6 square feet heating surface ; in a vertical tube pan from 2 to 2·2 square feet; in a lyre coil pan from 2·5 to 3 square feet, and in a Welner-Jelinek pan from 2·8 to 3 square feet.

Kind of Steam used.—In general, in modern factories, and always unless the engines are large steam consumers, all the exhaust steam is used up by the juice heater and multiple effect apparatus, and none remains for the pans. The majority of sugar manufacturers object with considerable reason to the use of high pressure steam in the pans, and consequently the main steam is reduced before entering the coils to a pressure generally lying between the limits of 10 lbs. and 20 lbs. per square inch. The objection to the use of high pressure steam is the tendency towards local overheating and caramelization of the sugar. This danger is not so great if the circulation is kept very rapid, and the use of high pressure steam adds very considerably to the capacity of a pan, the passage of heat being proportional to the difference in temperature between the exterior and interior of the coils; pans are now constructed, especially by United States firms, to work with steam pressures of 50 lbs. per square inch or even more, but it is really doubtful if the use of high pressure steam is to be advised.

In Chapter XVI., methods of steam economy, based on the use of the 'fore evaporator' and on the use of 'extra steam' are described; the steam of low temperature obtained in these schemes is in beet factories used as a source of heat in the pans; in such a case large heating surfaces become essential and it is important that the heating surface be as efficient as possible, a result to be obtained by the use of calandrias or of short length coils.

Special Devices in Pans.—Chiefly in the beet sugar industry many specialized types of pans have been designed; of particular interest are those designed for a slow methodical concentration of the low products to grain; these designs are exemplified in the *Freitag*, *Grosse*, and *Reboux* arrangements. The essential idea in these pans is a stirring device whereby the mass
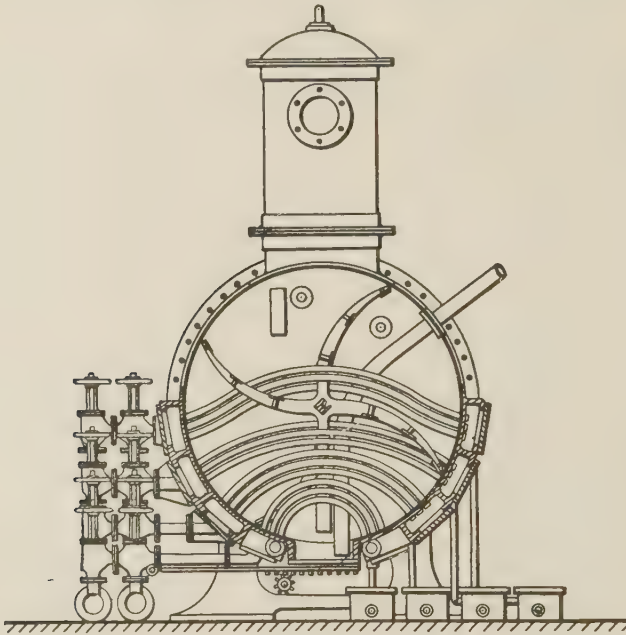
FIG. 194.

is kept in slow methodical movement; in the *Freitag* pan, the heating surface is a vertical tube calandria and in the *Grosse* pan, *Fig. 193*, a system of coils. The *Reboux* pan, *Fig. 194*, is peculiar in its arrangement and consists of a horizontal cylinder; the heating surface is made up of four separate systems of tubes. In all these pans the stirring device makes about four revolutions per minute.

With the object of obtaining a brisk movement of the thick viscid mass in a pan, arrangements have been devised whereby live steam or air is injected into the lower part of the pan; the injection of air was patented by Dr. Winter, of Java, to the end that on nearing the completion of a strike the partial

destruction of the vacuum, causing a rise in temperature, would effect the solution of small crystals, which would be recovered on subsequent cooling in motion.

The importance of a well distributed feed of the syrup is recognized in the Delavierre patent. In this arrangement a pipe is fixed around the saucer of the pan; this pipe communicates with the interior of the pan by a number of valves, the aperture of which is about one-sixteenth of an inch; the syrup is pumped into a receiver connected with the pipe on which are these valves; the syrup is injected into the pan through these valves in a number of fine jets whereby an extremely uniform distribution is obtained; with this device it is easy to obtain with but little attention a continuous feed of syrup into the pan.

Supersaturation.—A saturated solution of sugar or of any soluble body is one that can neither dissolve more sugar nor yet precipitate the dissolved body as long as the temperature and other conditions are maintained constant; in any case, if the conditions are altered either by removing water or by lowering the temperature, the separation of the sugar is not instantaneous and an unstable supersaturated condition results. If S be the solubility of sugar in water in saturated solution, and S_1 be the solubility in a supersaturated solution, Claassen terms the ratio $\dfrac{S_1}{S}$ the coefficient of supersaturation, and on this idea he has based a system of methodical pan boiling.

Before the granulation of the syrup in the pan can be obtained, a supersaturated solution must be formed, and the higher the coefficient of supersaturation at the granulation, the larger will be the number of crystals deposited, and consequently the smaller will be the size of the crystals on the completion of the strike; referring to beet sugar conditions, Claassen states that a coefficient of supersaturation of at least 1·2 is necessary, and that the average is 1·5 to 1·6; if a lower coefficient than 1·2 is used there is risk of redissolving the crystals on the addition of the next charge of syrup. During the process of growing the grain it is necessary that a uniform supersaturation be maintained throughout the entire mass, as otherwise the crystals will grow unevenly, and if a too high supersaturation obtain in any part of the pan a fresh crop of crystals (false grain) may form. The evaporation is greatest in those parts next the coils, and least in those parts next the inlet of cold syrup; hence, to obtain uniformity, the circulation of the mass and the distribution of the syrup must be controlled. Devices affecting these points have already been discussed, and it is well that the syrup should enter the pan at the least at a temperature not lower than that there prevailing. As a guide at this period, Claassen states that with a continuous feed of syrup a coefficient of supersaturation of 1·1 should be maintained, and that with an intermittent feed the supply of syrup should be cut off when the coefficient falls to 1, and opened when it rises to 1·2; finally, at the end of the strike the coefficient should be raised to 1·3.

Algebraical Theory of Sugar Boiling.—

Let x = Brix of the massecuite.*

s = solubility of sugar in the mother liquor or molasses.

p = purity of the massecuite.

m = purity of the molasses.

Then $(1 - x)$ = water in the massecuite.

$s\,(1 - x)$ = sugar in solution, *i.e.*, in the molasses.

$x\,(1 - p)$ = total non-sugar or impurities.

(For convenience of calculation these purities are referred to unity instead of to 100 as is usual.)

Then

$$m = \frac{s\,(1 - x)}{s\,(1 - x) + (1 - p)\,x} \qquad (1.)$$

and

$$x = \frac{s - ms}{s + m - ms - mp} \qquad (2.)$$

Let there be two massecuites of different purity, both boiled to the same degree Brix, the solubility of the sugar in the mother liquor remaining the same; then as p increases $1-p$ decreases, and the denominator in the expression (1) decreases, so that the value of m increases.

It follows then that as the purity of a massecuite increases, so also increases the purity of the mother liquor provided that the Brix to which the massecuites are boiled remains the same.

In the table below are calculated values of the expression:

$$\frac{s\,(1 - x)}{s\,(1 - x) + (1 - p)\,x}$$

for values of $x = {\cdot}90$, $s = 2{\cdot}0$ and $p = 75$ to 95, connecting purity of massecuite and purity of resulting molasses when the Brix of the massecuite is constant at 90 and solubility of sugar in molasses is $2{\cdot}0$.

Purity Massecuite.	Purity Molasses.	Purity Massecuite.	Purity Molasses.
75	44·44	86	58·82
76	45·45	87	60·60
77	46·51	88	62·50
78	47·62	89	64·51
79	48·78	90	66·67
80	50·00	91	68·96
81	51·28	92 .	71·43
82	52·63	93	74·07
83	54·06	94	76·92
84	55·55	95	80·00
85	57·14		

* In what follows Brix is here used as synonymous with true total solids.

Actually in practice the purer the syrup the higher is the degree Brix (*i.e.*, the sugar boiler brings up the strike higher) so that so great a difference in the purities of molasses from strikes of different purities will not be noticed. It is, however, a matter of experience that high purities in the strike imply high purities in the mother liquor or molasses.

The equation (2) above gives the degree Brix to which a massecuite must be boiled to give molasses of any desired purity when the solubility of sugar in the water remaining in the massecuite is known.

In the annexed table is calculated the degree Brix to which massecuites of purity 46 to 95 must be boiled in order to give a mother liquor of 46 purity when the solubility of sugar in the mother liquor is 1·8.

Values of the expression $100 \times \dfrac{s - ms}{s + m - ms - mp}$ for values of s 1·8 and m ·46, and of p ·46 to ·95.

p		p		p	
·46	79·65	·63	85·09	·80	91·35
·47	79·95	·64	85·44	·81	91·75
·48	80·25	·65	85·79	·82	92·15
·49	80·56	·66	86·14	·83	92·55
·50	80·86	·67	86·49	·84	92·96
·51	81·17	·68	86·85	·85	93·37
·52	81·49	·69	87·21	·86	93·79
·53	81·80	·70	87·57	·87	94·20
·54	82·12	·71	87·93	·88	94·62
·55	82·44	·72	88·30	·89	95·05
·56	82·76	·73	88·67	·90	95·48
·57	83·07	·74	89·04	·91	95·92
·58	83·42	·75	89·42	·92	96·35
·59	83·75	·76	89·80	·93	96·79
·60	84·08	·77	90·18	·94	97·24
·61	84·42	·78	90·57	·95	97·69
·62	84·76	·79	90·96		

Now, according to the equation, it is possible by boiling to a sufficient concentration to obtain in one process exhausted molasses; thus a syrup of 90 purity if boiled to a concentration of 95·48 Brix would, on the data on which the table was constructed, give molasses of 46 purity ; now from actual experience it is known that often four operations are necessary in general to obtain this end ; there is no real disagreement between theory and practice but the causes of this are :

1. It is impossible practically to boil any massecuite to so high a concentration as 95·48 ; a massecuite so highly concentrated would have no

circulation, it would bank up and burn on the coils and it would be a matter of difficulty to remove it from the pans and to manipulate it afterwards.

2. A very supersaturated solution of sugar would be formed in the final stages, from which, under the ordinary process of cooling at rest, sugar would separate with extreme slowness and in a form not suited to be recovered in the centrifugals.

By reducing the purity of a massecuite by the addition of molasses, exhausted or unexhausted, it is possible to boil the massecuite to such a concentration that all the sugar capable of recovery crystallizes out, and at the same time the massecuite is sufficiently fluid to be capable of practical manipulation.

On this argument all the schemes connected with crystallization in motion and return of molasses processes are capable of simple algebraical treatment.

Dependence of the Amount of Sugar crystallized on the absolute Amount of Water left in the Massecuite.—The

amount of sugar then that can be extracted as crystals from a massecuite depends on the degree Brix to which the massecuite can be boiled, or, conversely, to the least possible amount of water which can be left in the massecuite capable of retaining in solution the non-sugar, and it is immaterial, so far as regards the amount of sugar that crystallizes, whether the concentration is done in one or more operations. This is best shown by a worked out example.

Let there be a syrup of 80 purity, let it be concentrated to a Brix of 90 and let the solubility of sugar in the mother liquor be two, *i.e.*, for every one part of water in the mother liquor let two parts of sugar be dissolved.

Then the masse cuite is of composition—

Water	10
Sugar in solution	20
Sugar as crystals	52
Non-sugar	18
	100

Now let the 52 parts sugar as crystals be removed, leaving 48 parts of first molasses of percentage composition—

Water	20·83	
Sugar	41·66	
Non-sugar	37·50	
		100
Brix	79·17	
Purity	52·63	

and the sugar removed per cent. on that originally present is—

$$\frac{100 \times 52}{72} = 72 \cdot 22 \text{ per cent.}$$

leaving 27·78 per cent. in the molasses.

Now let these molasses be concentrated to a second massecuite at 90 Brix and let one part of water hold in solution two parts of sugar.

Then the percentage composition of the second massecuite is—

Water	10
Sugar in solution	20
Sugar in crystals	27·367
Non-sugar	42·633
	100·00

Now let 27·367 sugar in crystals be removed. Then per 100 sugar originally present there are removed.

$$\frac{27·367}{47·367} \times 27·78 = 16·07 \text{ per cent.}$$

and the total amount of sugar removed in the two operations per 100 sugar originally present is $72·22 + 16·07 = 88·29$.

Now to find to what Brix the massecuite must be boiled in one operation so as to leave the same absolute amount of water in the massecuite, we can proceed as follows. In the second massecuite above the non-sugar is 4·2633 times the water and the purity of the original syrup being 80, the sugar in the original massecuite is four times as much as the non-sugar. Let x be the water percentage in the massecuite boiled in one operation so that the absolute amount of water left is the same as that in the two operations above.

Then

$$x + 4·263x + 17·0532x = 100$$
$$x = 4·482$$

The composition of the massecuite boiled to this water content in one operation will be

Water	4·482
Sugar in solution	8·964
Sugar in crystals	67·450
Non-sugar	19·104

and if the 67·450 sugar in crystals be removed, the amount of sugar extracted per 100 sugar in the masse cuite is

$$\frac{67·450}{76·414} \times 100 = 88·29 \text{ per cent.,}$$

the same percentage as was obtained before in two operations.

Crystallization in Motion.[*] — A complete crystallization in motion or first-sugar and molasses process may be defined as "a scheme in which the purities of massecuites are reduced to such a point that they are capable of practical manipulation when concentrated to that point when the water left is only just sufficient to hold in solution the non-sugar, combined

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[*] As in other valuable processes there is no one inventor; Bocquin first in 1880 used a crystallizer as now understood; Wulff in 1884 gave a complete theory.

with the cooling of the massecuites in motion whereby the deposit of sugar from supersaturated solution is accelerated and takes place on crystals already formed."

The development of this scheme is traced below.

When a strike of grained massecuite leaves the pan a portion of the sugar is present as crystals and a portion is in solution; on cooling, sugar is deposited, and if the sugar is allowed to cool at rest new fine grain is formed which is incapable of recovery as first product; if such a strike is cooled in motion the crystals already present are continually brought into contact with fresh portions of the mother liquor and the sugar that is deposited forms on the crystals initially present. The first schemes of crystallization in motion had this for their object, and a very considerable increased return in first product was obtained without in any way altering the system of repeated boilings at that time general in cane sugar factories. Owing to the increased yield in first product a first molasses of lower purity resulted and where a factory took four boilings to obtain exhausted molasses the adoption of crystallization in motion reduced the number of operations to two or to three, besides obtaining a larger proportion of the output in the more valuable first product.

This point was made the subject of direct experiments by Prinsen Geerligs[3] in Java, who showed that a return of 64 per cent. of raw sugar was obtained from massecuites cooled in motion compared with an average of 56 per cent. from similar massecuites cooled at rest, although the actual amount of crystals present in all cases was very similar. This very simple scheme gives most pronounced benefit when impurer juices are being worked, as with these a more viscous mother liquor results and crystals deposited on cooling go to form new fine grain, the less viscous mother liquors obtained from purer juices allowing sugar separating on cooling to deposit on grain already present.

Although this scheme went far towards reducing the amount of low products it could not entirely suppress them, as the primary massecuites could not be boiled to a concentration so great that all the sugar capable of recovery separated, and various schemes have been devised to the end that all the output is obtained as high grade product. These schemes are discussed below.

Use of Exhausted Molasses.—Reference to the table of values of the expression $\dfrac{s - ms}{s + m - ms - mp}$ shows that for a purity of 90, the massecuite must contain 95·48 per cent. of solids if it should give exhausted molasses on curing; such a massecuite would be impossible to obtain or to work in the centrifugals; but if to such a (hypothetical) massecuite exhausted saturated molasses be added, no change in the massecuite, which can be itself

regarded as crystals and exhausted saturated molasses will occur; the two portions of molasses will mix and the magma will be sufficiently fluid to separate into crystals and molasses. On paper this scheme could be worked indefinitely, the exhausted molasses passing continually unchanged through the process and being regarded merely as a menstruum for obtaining a massecuite capable of manipulation. Actually, however, the continued action of elevated temperatures brings about obscure changes in the molasses which become 'gummy' and troublesome in the centrifugals.

Use of Unexhausted Molasses.—Chiefly in Java and hence known as the 'Java process,' a system of working has been developed which admits of the obtaining of all the available sugar in a merchantable form ; this can best be described by following through the details of the process. Initially let there be syrup of 80 purity ; per 100 massecuite obtained from this syrup there may be obtained 60 parts of crystals and 40 parts of molasses of 55 apparent purity ; let the next 100 parts of syrup massecuite be mixed with these 40 parts of molasses ; then a mixed strike of about 72 purity will result. From this strike molasses of about 45 apparent purity will accrue, there being probably equal quantities of molasses and crystals obtained, so that the factory now contains about 70 parts of molasses of about 45 purity. If to the next 100 parts of syrup masse cuite these 70 parts of molasses be added, a mixed strike of purity about 66 purity will result; this strike on curing should afford merchantable sugar and waste molasses of about 30 apparent or 45 true purity.

It is easy to see how the control of this process can be based entirely on the use of the algebraical theory developed above, that is to say, on the principle that for every purity of massecuite there is a corresponding water content at which exhausted molasses are obtainable.

The example detailed above suggests three operations as necessary to obtain exhausted molasses, at the end of which the cycle starts again ; in a number of factories the writer has seen the cycle reduced to two and even when the initial purity was nearly 90; in these cases no syrup massecuite was made but two strikes were boiled, one at a purity of about 75 and the other at about 60, the molasses from the latter being removed in part and in part used as a diluent for subsequent strikes. The writer prefers the first detailed scheme, but much depends on the factory arrangements, the nature of the juices, the kind of sugar desired, and the personel of the staff.

In all these schemes grain is formed from syrup and the molasses are added subsequently ; different ways of obtaining the mixture can be used.

1. All the syrup intended to be used may be taken into the pan at once, grain formed and the pan gradually filled up with the molasses

2. The molasses may be taken into the pan in one charge; in this method of working the syrup part of the charge is worked up in the usual way and brought up to the striking point; the predetermined quantity of molasses is then heated, very conveniently in a second pan, somewhat above the temperature of the syrup massecuite and cut over with the syrup pan; the molasses should enter at the bottom of the pan, so that it may rise through and mix with the syrup massecuite; the whole mixed strike is then concentrated to a degree corresponding to its purity and struck out.

3. The syrup and molasses may be mixed without the pan in carefully regulated proportion; this mixture may take place in the syrup tanks or the molasses may be mixed with the juice and pass through the evaporators.

Whichever method of working is used it is easy to see that all reduce to a scheme for the reduction of the purity of the massecuite to such a point that it can be boiled to a water content capable of manipulation and at the same time afford waste molasses.

Bock System.—This was one of the earliest systems put forward; in bare outline it is as follows:—A strike was boiled from syrup alone and struck out into crystallizers; two-thirds of this strike was cured as usual and the resulting molasses collected, boiled blank, and struck out on to the remaining third of the original strike, which was then cooled in motion and from which exhausted molasses was obtained.

First Sugar and Molasses.—Strictly speaking, any process known by this name should turn out one product only, separating the massecuites in one process into marketable sugar and waste molasses. This could on paper be effected by the use of exhausted molasses, all the strikes being boiled at a purity of 65 or thereabouts. Actually the writer believes such a method is not in any extended use. By the use of schemes described above all the sugar is obtained as a high grade marketable product although the term ' first sugar and molasses ' is not strictly applicable to it, since the two products obtained are not strictly of the same quality.

Reversed Process.—In the process described above the addition of molasses to a grain massecuite formed the basis of the scheme; a reversal of this process consists in taking unexhausted molasses and boiling them blank until they are of that degree Brix which will give exhausted molasses on cooling; to this masse cuite is added a quantity of sugar obtained from a previous boiling; the amount of sugar added is from 20 per cent. to 30 per cent. of the weight of the massecuite; the sugar is either taken into the pan or added to the massecuite after it has been struck out into the containers in which it is to be cooled in motion. This scheme, too, is easily seen to depend for its success upon the careful control of the water content of the massecuite boiled blank. The inception of this scheme is to be traced to Wulff's patent of 1884.

Crystallization in Motion of Low Products.—In some factories it is customary to cool in motion the low massecuites only after one or two lots of crystals have been obtained. In such cases the massecuites are usually allowed to stand until grain has begun to appear when they are subjected to a stirring which is continued for about a week; from this product a low sugar is obtained which usually is not marketed directly but is remelted and refined in the factory. Except for economy in floor space and for the saving of money lying idle, this process has nothing to recommend it; it is much inferior in results to the processes described above; its chief application lies in factories which make a high grade white sugar where the addition of molasses to the syrup is inadvisable.

Time for Cooling.—The strikes of higher purity are usually cooled for 12–15 hours; those of lower purity whence exhausted molasses are expected are cooled from 48–72 hours.

Crystallizer Capacity.—For a complete separation of massecuites into sugar and waste molasses 20 cubic feet of crystallizer capacity are required per long ton of sugar per week; less may serve but no margin is then allowed for the miscarriages which occasionally happen.

Technique of Crystallization in Motion.—This process gives great opportunity for observation and craft skill; some points are mentioned below.

Before taking molasses into the pan they should be cleaned by boiling in an eliminating pan and the scum which rises to the surface skimmed off; this heating will also dissolve fine grain.

The size of the pans and crystallizers should be correlated, so that a crystallizer takes a full or half charge of a pan.

For convenience of working all pans and tanks should be graduated, so that the operators can know exactly what quantities of syrup and molasses are in progress. During the process of cooling the massecuites should be inspected frequently and if they become too thick, hot exhausted molasses may be added as a diluent; an experimental centrifugal is very useful in following up the cooling process.

The stirrers should be completely immersed in the massecuites, else in their rotation they will force air into the massecuite which will form an emulsion and may make the molasses so light that they will not pass through the wall of sugar in the centrifugal baskets.

Control of the Water Content of Massecuites.*—It has been shown above that the success of these schemes depends on a knowledge of the water content of the massecuite when it is struck from the pan; this

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* See Note in Appendix.

datum can be obtained in the laboratory several hours after the strike has been finished, and in place of a laboratory analysis there is substituted the sugar boiler's sense of touch. In 1898 Curin[4] introduced into the beet sugar industry an instrument called the brasmoscope designed to control the operation of pan boiling and founded on the annexed principles.

Boiling point.—All liquids are constantly giving off vapour from their surface and when the pressure of the vapour equals that of the surrounding atmosphere the liquid boils; as the pressure of the surrounding atmosphere increases so does the boiling point of the liquid, and conversely with a fall of pressure there is a corresponding fall in the boiling point; when water or other liquid boils under a pressure less than that normally due to the atmosphere, it is said to boil under reduced pressure or less correctly 'in vacuo.' It is customary to express the pressure under which sugar solutions are boiled in 'inches of vacuum.' The normal pressure of the atmosphere will support a column of mercury 29·92 inches high; an absolute vacuum would then be expressed as 29·92 inches, and a vacuum of 25 inches will mean that the excess pressure of the atmosphere over the pressure in the vessel, in which there is a vacuum of 25 inches, is 29·92—25 = 4·92 inches. This method of expressing pressure less than one atmosphere is not altogether convenient, and for many reasons it would be better to speak of a pan being boiled under a pressure of 5 inches absolute, rather than as under a vacuum of 25 inches. In the Appendix is given a table connecting the pressures and temperatures at which water boils.

Effect of dissolved solids on the boiling point.—The boiling point is increased by the presence of dissolved solids and the following important relation connects boiling point, amount of dissolved solid and pressure under which ebullition occurs. 'The elevation of the boiling point due to the dissolved solids is independent of the pressure under which ebullition occurs.' For example, under a pressure of one atmosphere water boils at 212° F. and a 75 per cent. solution of sugar at 225·2° F. The elevation in the boiling point is then 13·2° F.; under a pressure of 4 inches of mercury (25·9 inches of vacuum) water boils at 125·6° F.; a 75 per cent. solution of sugar under the same pressure will then boil at 125·6+13·2 = 138·8° F. The temperatures at which sugar solutions of different concentrations boil under atmospheric pressure have been determined (see Table in Appendix); if then the temperature of a boiling sugar solution be known, and also the pressure under which ebullition occurs, then from the elevation of the boiling point over and above the boiling point of water under the same pressure, the amount of sugar in the boiling mass can be at once found. For example, under a pressure of 4 inches of mercury a sugar solution boils at 159·4° F.; water under this pressure boils at 125·6° F.; the elevation in the boiling point then is 29·8° F.; reference to the table of elevation of boiling points of sugar solutions gives the percentage of sugar as 86·25 per cent.

This relation is the basis of an instrument known as a brasmoscope or brixometer.

The brasmoscope consists merely of an accurate thermometer (the bulb of which is immersed in the boiling mass in the pan and placed so as not to be affected by local causes such as the proximity of a steam coil) and an accurate barometer pressure gauge, the ordinary aneroid gauges not being of sufficient accuracy.
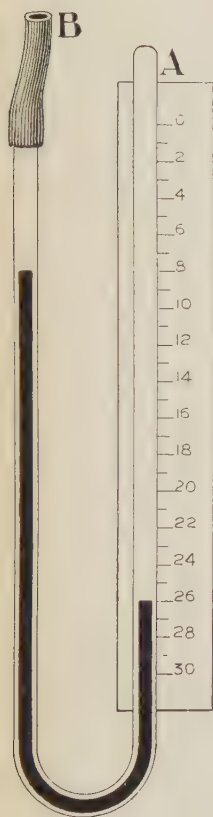
The form of barometer gauge usually found is a syphon barometer, *Fig. 195*; this consists of a U tube closed at the end A and open at the end B; the tube is filled with mercury and when held in a vertical position the difference of level between the mercury in the two limbs will give the pressure of the atmosphere in inches of mercury; this U tube is fixed on a board carrying a scale and is adjusted so that the level of mercury in the long limb is at the zero mark when under atmospheric pressure; if the open end be now attached to a vessel in which there is a reduced pressure, the mercury in the long limb will fall until the difference in level is that due to the pressure in the vessel connected to the short limb; the scale is so graduated as to give directly inches of vacuum in the vessel to which the short limb is attached. This instrument is not too convenient, as the gauge has always to be set at the zero mark and as a fall of pressure of, say, 1 inch in the vessel where the pressure is being measured only causes the level of the mercury in the long limb to fall half an inch, the level of the mercury in the short limb at the same time rising half an inch. The writer has devised the pressure gauge described below, *Fig. 196.*

FIG. 195.

A is a shallow receptacle of thick glass partly filled with mercury; on the upper side at B is a tubulure to be connected to the vapour space of the pan by stout rubber tubing; at C is the neck of the receptacle into which fits tightly the barometer tubing D, graduated in tenths of an inch; the receptacle A being filled with mercury the graduated barometer tubing is then inserted in the neck of the flask and mercury is sucked up above the level of the stop cock at E which is then closed; the mercury in A is then adjusted until its level is coincident with the zero mark on D; if then connection be made to the vapour space of a vacuum apparatus by way of B, the height of the column of mercury will directly measure the pressure in the pan.

After the pressure in the pan and the temperature of the boiling mass have been determined by reference to the tables, the elevation of the boiling point is found, and from this the apparent percentage of sugar in the boiling mass is determined.
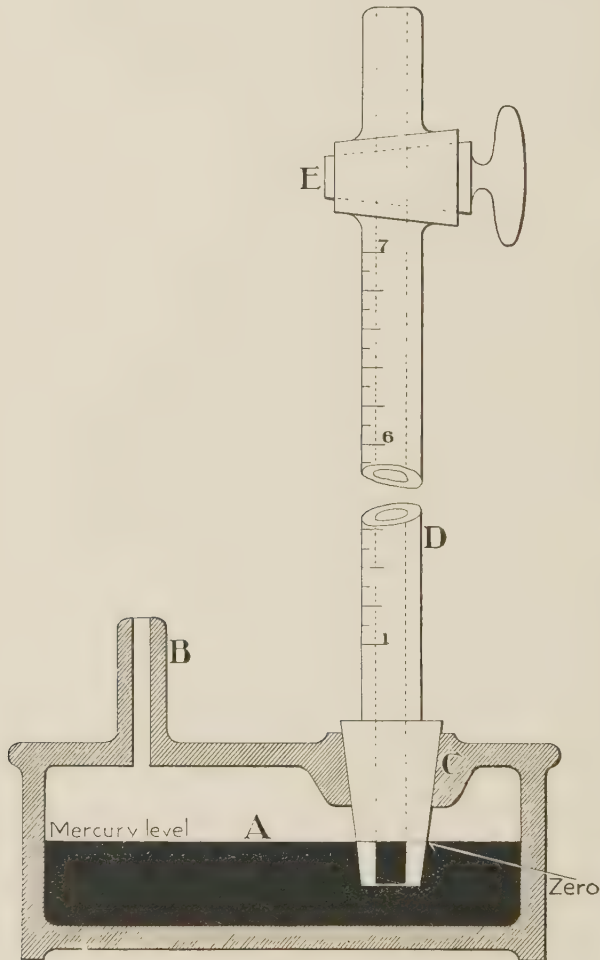
FIG. 196.

Instead of using tables, Claassen has devised a mechanical scale for determining the apparent percentage of sugar. In *Fig. 197*, A, B and C are three scales; A and C are fixed and B is a sliding scale; A is the vacuum scale and C is the temperature scale; C is graduated in equal divisions

FIG. 197.

corresponding to the divisions of a thermometer ; on A, opposite to the temperature divisions on C, are marked the corresponding pressures or vacua at which water boils. The sliding scale B is graduated so as to connect the elevation of the boiling point with the amount of sugar present, on the same basis as the divisions in the scale C. A determination is actually made as under.

The vacuum in the pan is 28·0 inches and the temperature is 140° F. The zero on the scale B is placed opposite 28·0 on the scale A; the division on the scale C corresponding to a temperature of 140·0° F. is then noted, and opposite this on the scale B is the division 89·9, $i.e.$, the boiling mass contains apparently 89·9 per cent. of sugar.

It may at once be stated that it is only bodies in solution that affect the boiling point, and that sugar that has crystallized out has no effect at all ; it is only then with masses boiled string-proof that the apparent sugar percentage of the whole mass is given ; in other cases it is the apparent sugar percentage of the mother liquor. The scales in the brasmoscope are calculated on a sugar basis, and give only the apparent percentage of total solids expressed as sugar, exactly as the Brix spindle gives also apparent total solids; actually the non-sugar causes weight for weight a greater elevation of the boiling point than does the sugar, so that the brasmoscope indication will always be higher than the true total solids, and this will be the more pronounced the impurer the mass that is being tested.

Application of the Brasmoscope.—The simplest instance of the use of the brasmoscope lies in its application to low products boiled string-proof; here no sugar separates in the pan as crystals, and the indications of the instrument will now refer to the Brix*

* Brix in what follows is used as synonymous with the true total solids.

of the whole mass in the pan. Suppose it has been found by experience that a mass of 50 apparent purity gives the best results when boiled to an apparent Brix, as indicated by the brasmoscope, of 90; when this factor has once been determined it is an easy matter to boil all subsequent strikes of this purity to the same elevation of the boiling point, and this can be done more exactly with the aid of graduated instruments than by the sense of touch of the most experienced sugar maker ; the illustration given above demands, of course, that the nature of the non-sugar does not vary.

From the formula or table it follows that a massecuite of 50 purity concentrated to 80·86 Brix will give molasses of the same purity as one of 55 when concentrated to 82·44 Brix. The ratio between these two Brix is 82·44 ÷ 80·66 = 1·0195. Hence the required Brix as indicated by the brasmoscope is 86·5 × 1·0195 = 88·19, *i.e.*, if a massecuite of 50 purity gives molasses of 46 purity when concentrated to 86·5 Brix as indicated by the brasmoscope, a massecuite of 55 purity will give molasses of the same purity when concentrated to 88·19 as indicated by the brasmoscope.

The application of the brasmoscope readings to control the water content of massecuites boiled to grain is complicated in that the instrument does not give the Brix of the massecuite as a whole but of that of the mother liquor ; what is required to be known may be expressed thus : What shall be the Brix of the mother liquor in the pan at the moment of observation so that on cooling exhausted molasses result ? And algebraically the problem can be solved thus :

Let the solubility of sugar in molasses at a low temperature be s and let it be s' at a more elevated temperature ; it is required to find what must be the Brix when the solubility is s' so that the purity is m when the solubility is s. Let x be the Brix of the molasses when the solubility of sugars is s.

Then

$$1 - x = \text{water}$$
$$s\,(1 - x) = \text{sugar}$$

and

$$m = \frac{s\,(1-x)}{x}$$

whence

$$x = \frac{s}{s + m} \tag{1}$$

Now let the solubility of sugar change to s', all other factors remaining the same.

The absolute amount of sugar in solution now is $s'\,(1 - x)$, the water and non-sugar remaining the same.

If the Brix be now denoted by x',

$$x = \frac{s'\,(1-x) + \{\,x - s\,(1-x)\,\}}{s'\,(1-x) + \{\,x - s\,(1-x)\,\} + 1 - x}$$

For s put $s + d$, d being the difference in the solubility of sugar at the two temperatures.

Then

$$x' = \frac{d + x - dx}{1 + d - dx}$$

But x has already been shown to be equal to

$$\frac{s}{m + s}$$

Making the substitution

$$x' = \frac{d + \dfrac{s}{m + s} - \dfrac{ds}{m + s}}{1 + d - \dfrac{ds}{m + s}} = \frac{s - dm}{s + m - dm} \tag{2}$$

As a numerical example let the solubility of sugar be 1·8 and let molasses of 46 purity be required; the Brix of these molasses will be from equation (1)

$$\frac{100 \times 1{\cdot}8}{1{\cdot}8 + {\cdot}46} = 79{\cdot}64.$$

Now let the solubility of sugar become 2·5 so that d is ·7. The Brix of the molasses then is from equation (2)

$$100 \times \frac{2{\cdot}5 - {\cdot}7 \times {\cdot}46}{2{\cdot}5 + {\cdot}46 - {\cdot}7 \times {\cdot}46} = 82{\cdot}57$$

Unfortunately the solubility of sugar in the hot mother liquor (s' in the equation established above) in the pan can not be exactly known; it is affected by the temperature prevailing, by the presence of non-sugar and by the degree of supersaturation; now at the temperature 40° C at which it is customary to cure massecuites boiled to grain and cooled in motion the solubility of sugar in water is 2·38 and at the temperature 70° C which is approximately that of the massecuite in the pan the solubility is 3·20; the ratio of these is 1·34; previously the solubility of sugar in exhausted molasses was taken as 1·8, at a temperature of 27° C; between 27° C and 40° C the solubility of sugar in water increases in the ratio 1·11, and hence at 40° C the solubility of sugar in molasses is taken as 1·11 × 1·8 = 1·998 and at 70° C 1·998 × 1·34 = 2·68; cutting off the decimals then the values of s and s' in the equation established above will be taken as 2·0 and 2·7.

Now owing to supersaturation the lowest solubility possible in the pan at the temperature of 70° C will be 2·7 and it may be considerably higher.

Values of the equation

$$\text{Brix} = \frac{s - md}{s + m - md}$$

for values of $s = 2{\cdot}0$, $d = 0$ to 1·3 ($s' = 2{\cdot}7$ to 4·0) and $m = 38$ to 50 have been calculated and are given in the table below; in the vertical column on the left hand side are entered the solubilities of sugar in the molasses in the pan; in the horizontal caption are entered the values of m from 38 — 50;

Purity of Molasses with Solubility, 2·0

Solubility of sugar in pan.	38	39	40	41	42	43	44	45	46	47	48	49	50
2·7	84·93	84·65	84·37	84·14	83·48	83·37	83·31	83·05	82·80	82·55	82·30	82·06	81·81
2·8	85·15	84·88	84·62	84·35	84·09	83·83	83·58	83·33	83·09	82·85	82·61	82·37	82·14
2·9	85·37	85·11	84·85	84·59	84·34	84·09	83·85	83·61	83·37	83·13	82·90	82·65	82·46
3·0	85·58	85·33	85·07	84·82	84·58	84·34	84·10	83·87	83·64	83·42	83·19	82·98	82·76
3·1	85·79	85·54	85·29	85·05	84·81	84·58	84·35	84·13	83·91	83·69	83·47	83·26	83·05
3·2	85·99	85·75	85·51	85·27	85·04	84·82	84·60	84·38	84·16	83·95	83·74	83·53	83·33
3·3	86·18	85·95	85·72	85·49	85·26	85·04	84·83	84·62	84·41	84·20	84·00	83·80	83·60
3·4	86·37	86·14	85·91	85·69	85·47	85·26	85·05	84·85	84·65	84·45	84·25	84·06	83·87
3·5	86·55	86·33	86·11	85·89	85·68	85·48	85·27	85·07	84·88	84·70	84·50	84·31	84·13
3·6	86·73	86·52	86·31	86·09	85·89	85·69	85·49	85·29	85·10	84·92	84·73	84·55	84·37
3·7	86·90	86·69	86·49	86·29	86·09	85·89	85·69	85·50	85·32	85·14	84·97	84·79	84·62
3·8	87·07	86·87	86·67	86·47	86·27	86·08	85·89	85·71	85·53	85·36	85·18	85·02	84·85
3·9	87·24	87·04	86·84	86·65	86·46	86·27	86·09	85·92	85·74	85·57	85·40	85·23	85·07
4·0	87·40	87·20	87·01	86·83	86·64	86·46	86·11	86·11	85·94	85·78	85·61	85·45	85·29

the figure at the intersection of a vertical and horizontal line gives the degree Brix of the molasses in the pan, so that when the solubility of sugar becomes 2·0 molasses of the purity in the column selected will result. As an example the solubility of sugar at the moment of observation is 3·0 and it is desired to obtain molasses of 40 purity when the solubility is 2·0 ; at the intersection of the line 30 and 40 is the figure 84·82, *i.e.*, the Brix of the molasses in the pan must be 84·82.

As pointed out in dealing with the application of the brasmoscope to massecuites boiled string proof, it is impossible to state beforehand what the indication of the brasmoscope should be, and the brasmoscope indications must be systematically compared with the actually recorded results in the factory. When once the brasmoscope indications corresponding to molasses of a satisfactory low purity are obtained, then it should be possible to reproduce those conditions more exactly than can be done by the senses of sight and touch.

The process of exhausting rapidly low grade massecuites mentioned above as 'reversed process' would appear to be a scheme lending itself readily to a very complete control, as it would only be necessary to determine the proper concentration of the low grade massecuite before taking in the sugar used as 'priming,' as has already been indicated when dealing with the application of the brasmoscope to massecuites boiled string proof.

Control of the Supersaturation.—As the supersaturation rises so also does the elevation of the boiling point; when once the most favourable degrees of supersaturation for the different periods of the process of concentration in the pan have been determined, they may be referred to elevation of the boiling point, and it is thus possible always to boil the pan under equal conditions. For example, suppose it is desired to work with a continuous feed, and it has been found that, with a boiling point elevation of 20° C. the best results are obtained; the feed and steam valves are so set that this elevation is maintained as indicated by the brasmoscope reading; should a low elevation be observed it is evident that syrup is being admitted too fast, *i.e.*, the supersaturation is diminishing. Similarly the granulation and the bringing up can be worked with a prearranged supersaturation as indicated and controlled by the brasmoscope indication. Actually in the majority of cases the skilled sugar boiler makes these observations by the senses of sight and touch, and for these the brasmoscope substitutes a definite scientific relation.

Use of the Refractometer.—The methods by which the total solids in sugar house products are obtained with this instrument are given in Chapter XXIII. This instrument is particularly serviceable in determining in a very short space of time the concentration of the massecuite in the case of strikes boiled blank. The sample of material removed in the proof stick serves for the determination, which can be made in two minutes. This instrument gives a most valuable control over the whole process of pan boiling.

Special Treatment of Low Massecuites.—The time required for a complete crystallization of low grade products may be shortened by distributing over the surface of the massecuites a quantity of sugar crystals which are allowed to slowly fall through the massecuites; the quantity of crystals used is about 1 per cent. on the weight of the massecuite.

Crystallization in motion on a new basis has been applied in recent years to low massecuites by means of air injection; compressed air is introduced at the bottom of the tanks containing massecuite by means of a rubber hose. The treatment is begun after the massecuites have stood for 48 hours; at first they are treated daily, then twice a day, and eventually every three hours.

Calculation of Proportions of Syrup and of Molasses to be used to obtain a Strike of prearranged Purity.— Let the volume of the whole strike be unity and that part due to the syrup be x. Then $1 - x$ is the volume due to the molasses. Let p be the desired purity of the strike and p_s and p_m be the purities of the syrup and of the molasses.

$$\text{Then } p = p_s x + p_m (1-x); \text{ whence } x = \frac{p - pm}{p_s - pm}$$

Example.—It is desired to obtain a strike of 65 purity from syrup of 80 purity and molasses of 45 purity.

The volume of the strike due to syrup is then $\frac{65 - 45}{80 - 45} = \cdot 571$.

If the whole volume of the strike is 1000 cubic feet the pan will be filled up to 571 cubic feet with syrup massecuite and the strike completed with 429 cubic feet of molasses. This calculation supposes that the percentage of solids in the syrup massecuite before drawing over the molasses and in the molasses are the same.

Effect of Size of Grain.—The smaller the grain the larger is the exposed surface and the greater the area of crystal surface that comes in contact with the mother liquor within a given time; hence the rate at which the desaccharification of a mother liquor proceeds is greater in a small grained massecuite than in one with larger crystals; it is only however the time that is affected, as the total amount of sugar that separates is solely determined by the water content of the massecuite. In addition, with the larger exposed area of crystal surface, there will be less chance of a deposit of fine or of false grain, and for this reason a small grained massecuite can be safely cooled at a greater rate than can a larger grained one.

Rapidity of Cooling.—The rate at which a body cools is within certain limitations proportional to the excess temperature; hence immediately after striking the rate of cooling is greatest; if the massecuite cools faster than sugar can deposit, the coefficient of supersaturation increases, and there is danger of the formation of fine grain due to the sudden deposit of crystals from a very supersaturated solution, the sugar so depositing not forming on

crystals already present. It should be the object of the sugar maker to so control the rate of cooling that the supersaturation does not increase, and that the deposit of sugar keeps pace with the rate at which the massecuite cools. The advantage of jacketed containers in a crystallization in motion process is connected with the point explained above; namely, that a means is provided whereby the rate of cooling can be controlled.
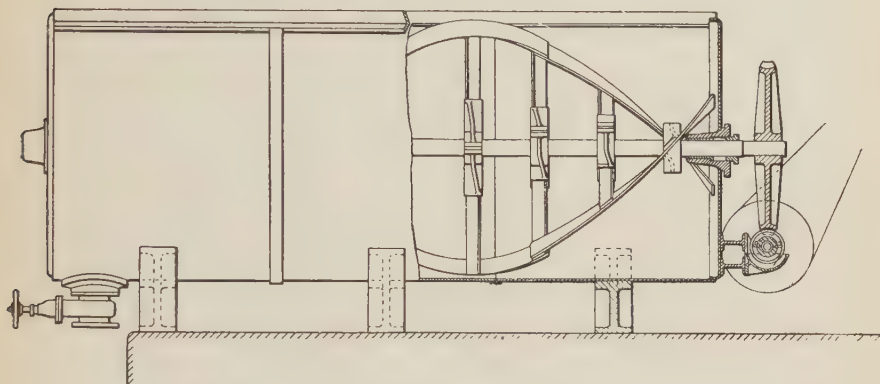
Fig. 198.

Forms of Crystallizing Tanks.—The receptacles in which the massecuites are received in order to be cooled in motion are either U shaped or cylindrical horizontal vessels; they are constructed of boiler plate, and are made either closed or open. Through the centre of the vessels passes a shaft to which is attached the stirring apparatus; motion is usually transmitted to this shaft by means of a wheel and worm gear, the wheel being attached to
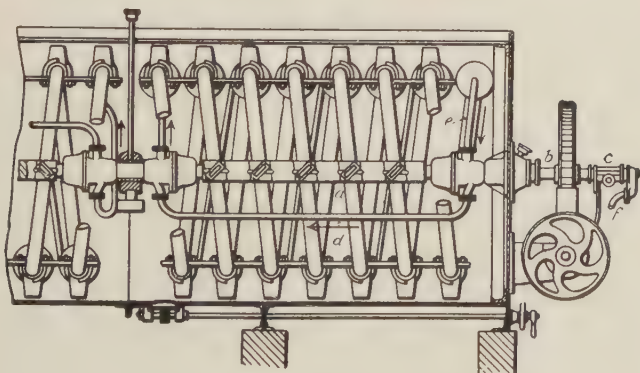
Fig. 199.

one end of the shaft; the tanks are so arranged that one worm gears with the wheels of the whole battery. The tanks are made either plain or provided with a jacket, into which steam or water can be admitted, and thus control the rate at which the massecuite cools. A general form of crystallizing tank is shown in *Fig. 198*.

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Of special designs of crystallizers may be mentioned :—

Ragot and Tournour's.—This is shown in *Fig. 199.* The stirring gear in this pattern is a hollow helical coil through which steam, hot water or cold water can be passed. On one end of the shaft is a hollow shaft *b*, to which is connected a steam or water distributing box *c*. The steam or water passes into an annular space in the pipe *b*, thence by way of a pipe *d* to the coils, returning through the pipe to the outlet *f*.
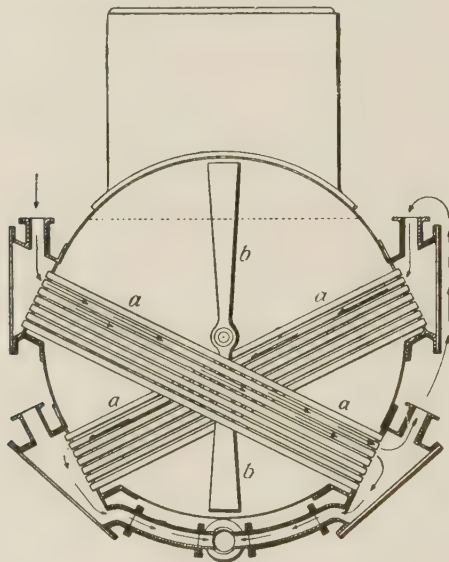
FIG. 200.

Huch Crystallizer.—This is shown in section in *Fig. 200.* It con_ sists of a closed cylindrical vessel surmounted by a dome; in this vessel are arranged the tubular elements *aa* which may be used as heating or as cooling surfaces; the path of the stream or water is shown by the arrows; the stirring device is shown at *b*.

REFERENCES IN CHAPTER XVII.

1. *Beet Sugar Manufacture*, p. 149.
2. *Bull.* 16, *Agric. H.S.P.A.*
3. *S. C.*, 309-311.
4. *Sucrerie Belge*, July, 1898.

CHAPTER XVIII.

THE SEPARATION OF THE CRYSTALS.

The finally concentrated product of the juice (massecuite) consists of a magma of sugar crystals and a thick viscid solution of sugar, and of all the bodies present in juices. The crystals are separated from this magma by means of machines known as centrifugals or hydro-extractors. Formerly— and to some extent still—the molasses were allowed to drain from the massecuite, which was packed in hogsheads with perforated bottoms.

Receptacles for, and Transport of, Massecuites. *Tank System.*—The first massecuites are emptied into shallow wooden or iron tanks arranged on the basement; from these tanks directly, or after cooling, the massecuite is dug out and carried by hand to the centrifugals; this arrangement is now but seldom found for first sugars, but still remains very common for low sugars, which may be stored for periods up to a whole year.

Tank Tramway System.—The massecuites are emptied into tanks holding up to 100 cubic feet, which run on tram lines and are hence capable of being wheeled to the centrifugal battery, where their contents are emptied by manual labour; alternately these tanks may discharge into a pit, whence the massecuite is elevated by a chain or magma pump; or the tanks may be on an upper floor and may discharge their contents by gravity.

Small Can System.—The massecuite is discharged into cans holding about 500 lbs.; these cans are transported by means of trolleys, elevated by means of an hydraulic lift, turned bottom upwards and their contents discharged by compressed air, a small hole being arranged in the bottom wherein is inserted the nozzle of a pipe communicating with an air compressor. This system has been and is still largely used, and in many ways is very convenient; it demands, however, extensive floor space.

Gravity System.—The pans are built on a high floor and discharge into receivers, whence the massecuite flows by gravity to the pug mill of the centrifugals.

Compressed Air System.—The massecuites are received in closed vessels and are conveyed in pipes by compressed air to the centrifugals; this method is very clean, but demands a fluid massecuite or one thinned with molasses. These two last schemes are used frequently with crystallization in motion.

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The Centrifugal Machine.—A centrifugal machine consists essentially of a vertical cylindrical perforated basket, which is caused to revolve at a high rate of speed; within the perforated basket is fixed a wire gauze strainer, containing from 400 to 500 perforations per square inch. The revolution of the basket throws the magma of crystals and molasses against the side of the basket; the molasses and a portion of the crystals pass through the gauze, and the great portion of the crystals are retained; without the perforated basket is a casing which catches the molasses and directs them by a spout into the gutter.

Types of Centrifugals.—Centrifugals were perhaps introduced into the sugar industry in 1849, by Dubrunfaut, and now a large number of
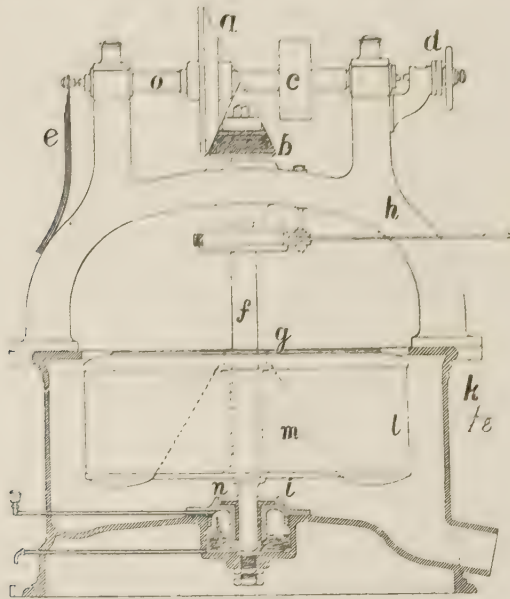
FIG. 201.

types are to be found; mainly they fall into two classes, fixed bearing pattern and suspended pattern; again they may be divided into under and over-driven machines, or according to the method of driving, direct coupled, friction cones, belt, electric, or water drive.

Fixed Bearing Friction Cone Machine.—In *Fig. 201* is shown a view of this type of machine; *f* is the spindle revolving in two brasses, *i* and *j*, the lower brass *i* being fixed in the bottom of the monitor outer casing *k* and the upper one *j* in the cross piece of the frame *h*, which is supported on and bolted to the outer case; the basket *l* is secured to the spindle by the nut *g*, screwed down on the cone *m*, which rests on the bottom of the basket; a collar *n* on the spindle prevents any downward movement.

Motion is transmitted to the machine by a belt drive on the pulley *c*, and by the friction cones *a* and *b ;* the driving cone *a* is of steel, and the driven cone *b* of mill board ; the driving spindle *o* is carried on two bearings, the cones being kept in contact by the pressure of the spring *e* on one end of the spindle ; the cones are thrown out of gear by means of the screwed piece *d* moving the spindle outwards against the pressure of the spring.

Belt-driven Pivot Machine.—In *Fig. 202* is shown a type of pivot under-driven machine, which, equally with the above, is common on the Continent of Europe and wherever the influence of Continental engineers is felt. The basket *a* is fixed to the spindle *c*, which is supported by the footstep
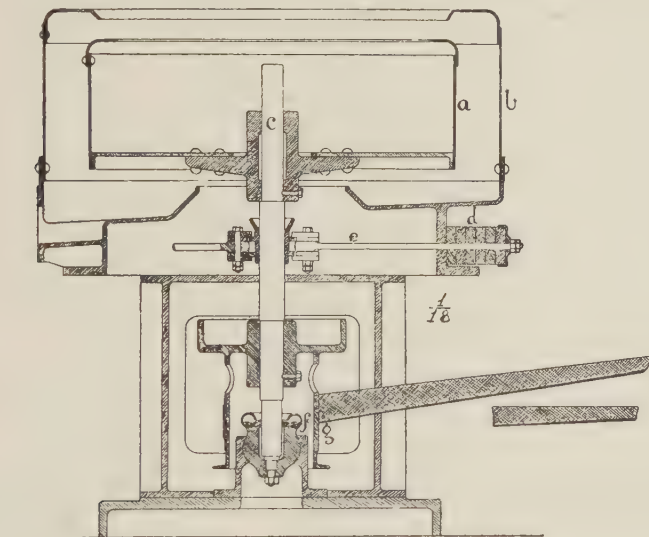
FIG. 202.

bearing *f*, and the collar formed by the iron bars *e ;* these bars are screwed up against pieces of indiarubber *d*, whereby the shock of the machine is partly absorbed. The machine is driven by belt drive on the pulley *g*.

Weston Suspended Centrifugal.—All machines of the types above described use a large part of the power supplied in keeping the revolving basket in a fixed position. In 1852 David Weston invented and made in the Hawaiian Islands the first suspended centrifugal which has since become the standard pattern in cane sugar factories ; beet factories in Europe were (and still are) slow to adopt this pattern. In *Fig. 203* is shown a section of the *Weston* type of centrifugal machine as arranged for belt drive. SB is the suspending block firmly bolted to an overhead beam or framing CF ; EB are elastic buffers resting on the block SB, and above this is suspended from the elastic buffers the spindle IS by means of a top nut and washer ; this spindle oscillates with the machine, but does not revolve ; at BB is shown the bottom revolving bearing ; at OS is shown the outer revolving spindle attached
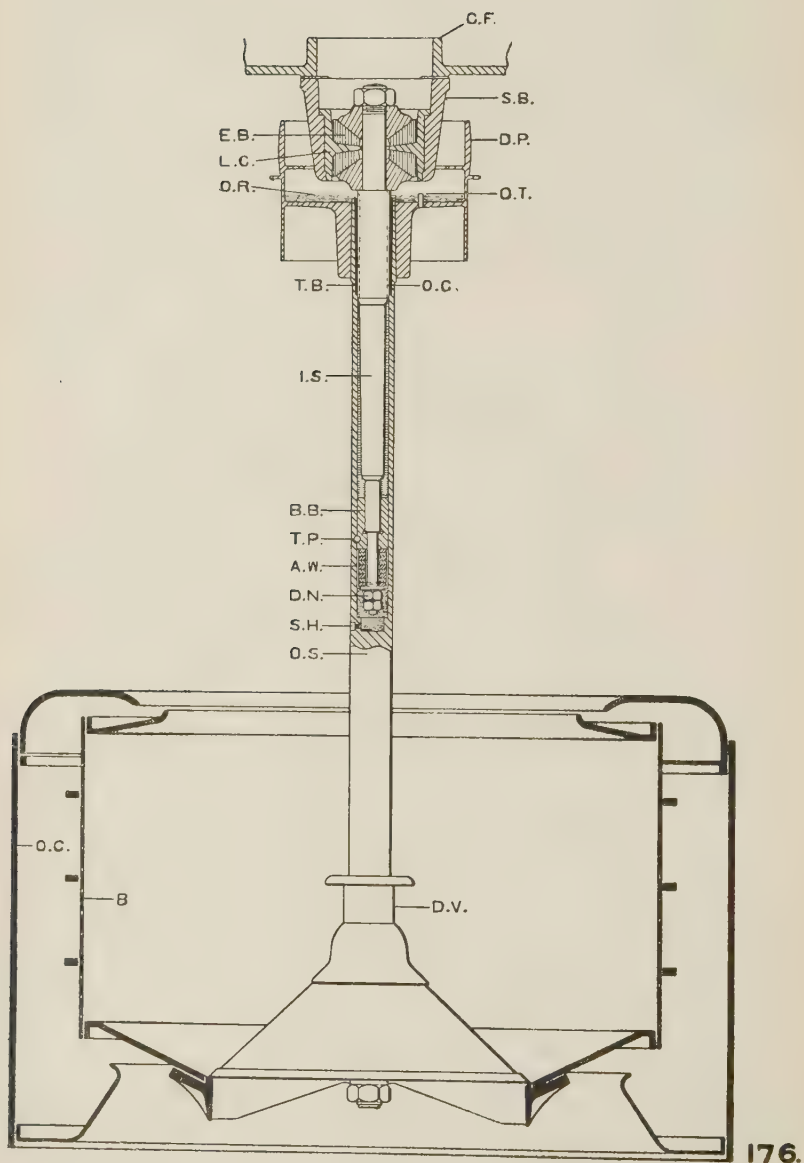
Fig. 203.

to the driving pulley DP.   The perforated basket is shown at B, and the outer casing at OC ; and sugar is discharged through a circular aperture at the bottom of the basket, kept closed when necessary by the valve DV, which slides up and down the outer spindle ; the bottom part of the outer spindle forms an oil bath.   The elastic buffers are an essential feature of this type of centrifugal.   The massecuite will from time to time assume different centres
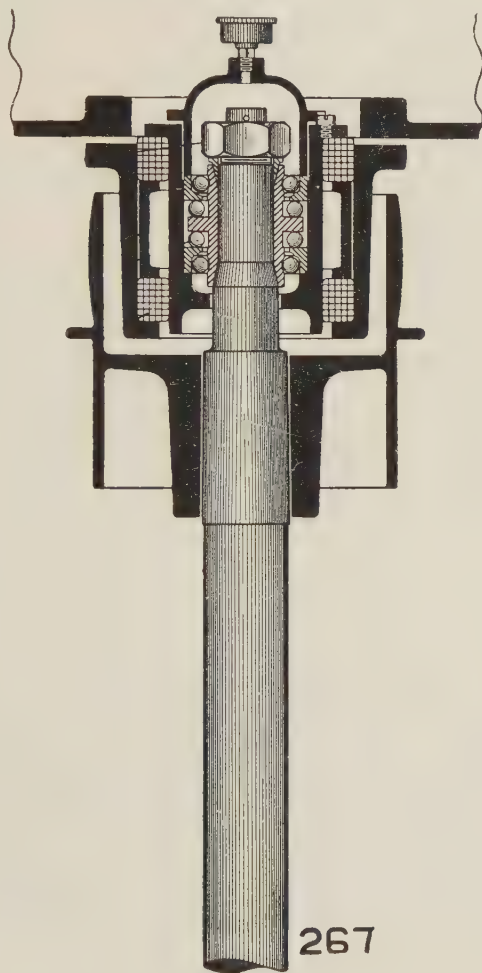
Fig. 204.

of gravity ; instead of attempting to restrain the machine in a fixed position this system allows a certain freedom of movement.

A solid spindle has in recent years been generally substituted for the hollow spindle, and after several failures ball bearings have been successfully adapted to this machine ; in *Fig. 204* is shown the upper part of a belt-driven machine embodying these improvements.

Hepworth Suspended Centrifugal.—The *Hepworth* suspended centrifugal differs from the above in that the whole machine is suspended; referring to *Fig. 205*, it will be seen that *a* is the ball of a ball and socket joint formed in the bracket *m*, from which pass three or four rods *k* which support the outer casing *d* of the machine; the bracket *n* is so formed as to make a reservoir of oil; the spindle carrying the revolving basket *g* is shown
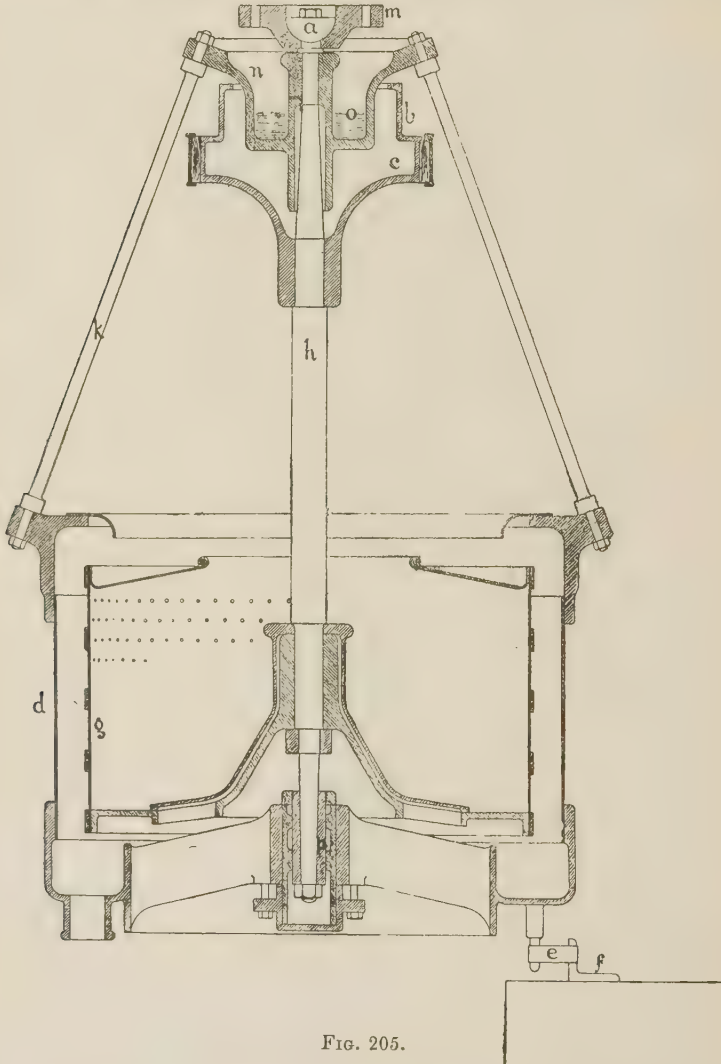
FIG. 205.

at *h*; this spindle works in two bearings seen at *o* and *p*; the brake is seen at *c*, and the brake band at *l*; cast on the bottom of the outer casing are lugs on which are placed indiarubber bands *e* passing over the fixed brackets *f*; these indiarubber bands are for the purpose of controlling the movements of the machine, and at the same time allowing a certain freedom of movement.

PLATE XVIII.

4036   4062

FIG. 207.

Plate XIX.
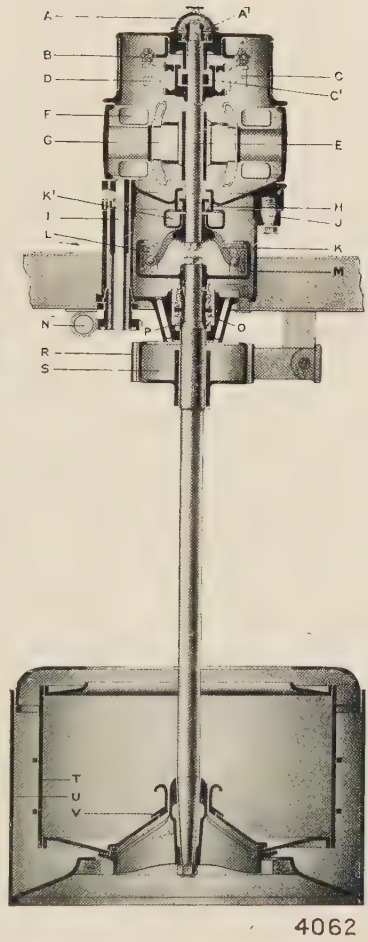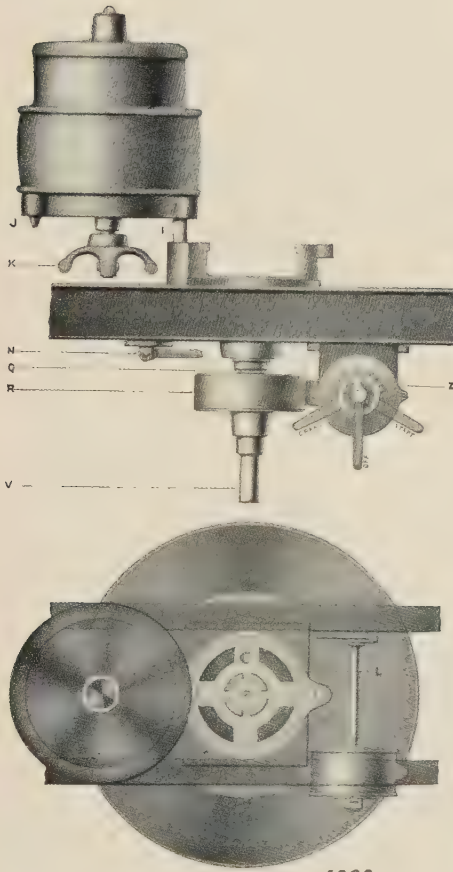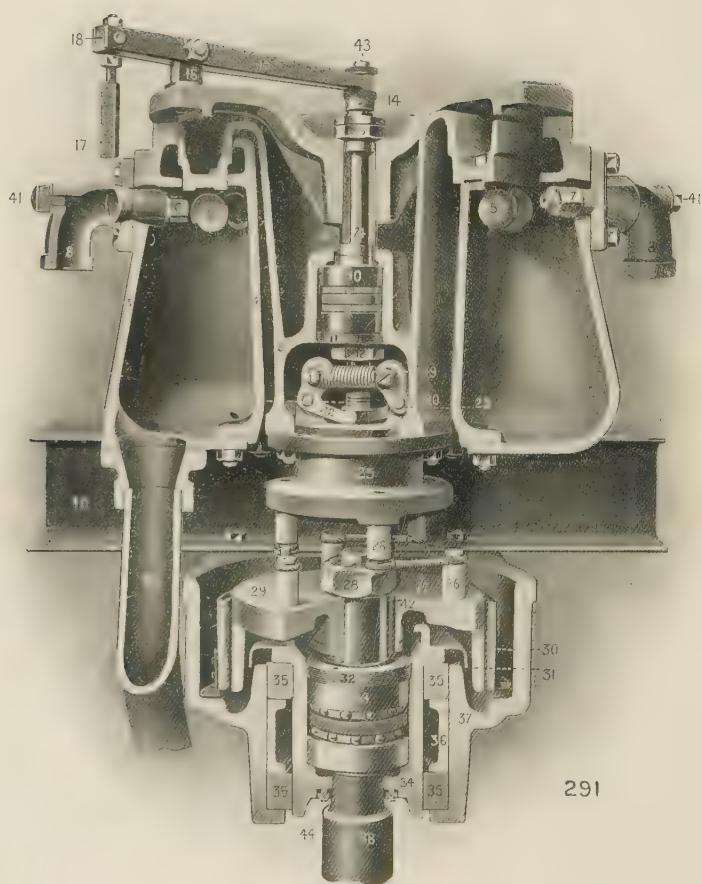
FIG. 209.

Motive Power for Centrifugals.—Until recent years a belt drive was the usual method of driving centrifugals but latterly many installations have adopted a water or electric drive. In *Fig. 206* is shown a view of an electrically driven spindle as made by Messrs. Pott, Cassels and Williamson. The lettering is as under:—C inside spindle, D intermediate spindle, H top plate of motor case, K armature, L magnet coils, M brake, O commutators, P brushes, Q driving disc, R friction arms, S pulley, T brake pulley. On switching on the current the magnet coils pull off the brake and the armature being loose on the outer spindle immediately revolves at a high speed and gradually communicates motion to the spindle V by means of the friction arms which are pressed out against the pulley.

In *Fig. 207* (PLATE XVIII.) is shown a view of the electric-driven spindle as made by Messrs. Watson, Laidlaw & Co. The lettering is as follows:—C brushes, D commutator, E motor spindle, F field coils, G armature, L friction shoes, N worm and wheel, R brake, T inner revolving spindle, U stationary sleeve, V outer revolving spindle, Z switch.

In *Fig. 208* is given a view of the water-driven machine of Messrs. Watson, Laidlaw and Co. This type of machine has in recent years been very extensively adopted. The head of water necessary to drive the machine is obtained from a double acting pump; no large supply is needed, as after discharge from the Pelton wheel fitted on the outer spindle, the water flows back to the supply tank of the pump. Two jets are supplied, and after full speed has been obtained, one is automatically cut off; if it is desired to get up speed slowly one jet only is used, an advantage in curing low-grade products.

The motor and centrifugal head of the water-driven machine of Pott, Cassels and Williamson is shown in *Fig. 209* (PLATE XIX); the reference being as follows:—38 centrifugal spindle; 33 ball-bearing; 35 rubber buffers; 29

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FIG. 206.

Main Pressure Pipe

Patent self-adjusting
conoidal Buffer

Housing containing
patent compound
ball bearing

Pelton Wheel

Supporting Beams

Brake Pulley

Spindle

Position of Discharge Valve
when Basket is being emptied

Lip

Basket

Outer Case

Discharge Valve

Discharge

Opening

Cloth flap
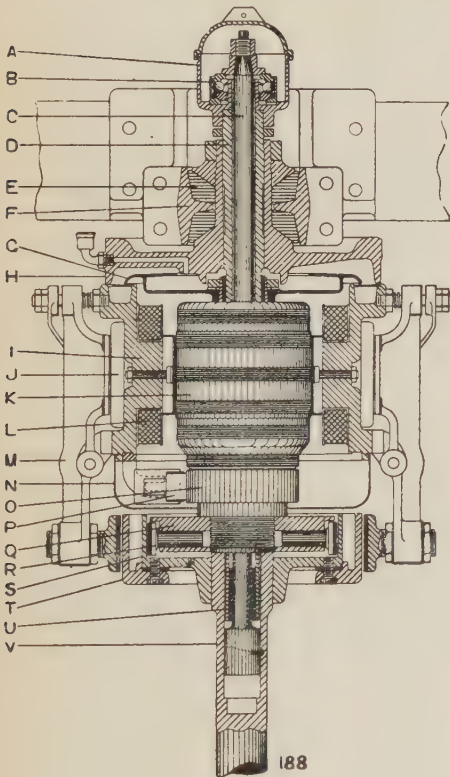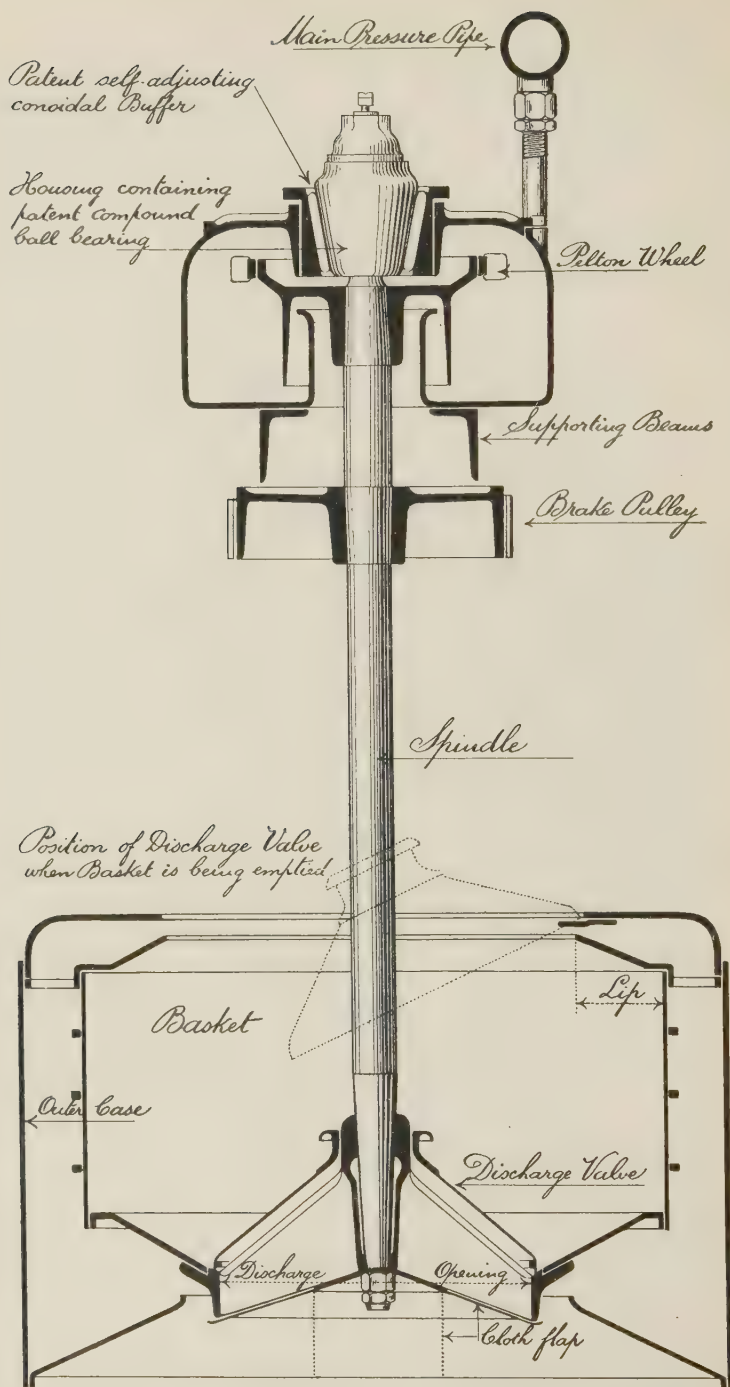
4148

FIG. 208.

brake pulley; 30 brake band; 37 bracket carrying the centrifugal suspended from the I beam 40; 3 and 4 motor case; 10 ball-bearing; 2 water wheel; 5 hemispherical caps upon which impinge the water jets 6 and 7 of which 6 is the accelerating and 7 is the maintaining jet; 39 waste pipe; 25 governor controlling the supply of water when full speed has been obtained; 27 wire rope links connecting motor to centrifugal.

These machines are made in pairs with an interlocking gear so designed that only one of a pair of machines can be accelerated to speed at one time.

In plants of earlier date where the whole battery of centrifugals was driven by belt drive, the whole ratio of gearing between engine and machine is from 300 to 400 to 1; with such an arrangement any variation in the speed of the engine is multiplied in the centrifugal and means of varying the speed of a machine or of distributing the power according to the demands on it are impossible; with the interdependent water and electrically driven machines the power supplied varies according to the demand; thus with the water drive two jets are employed both of which act when the machine is starting and when the effort is greatest; afterwards only one jet is in action. A similar principle is embodied in the electric driven machines; this action is of use too in curing low grade sugars which often are found to purge best when speed is got up slowly; cost of up-keep and freedom from danger are also points in favour of the direct motor driven types.

Size of Basket.—Within the last decade the size of basket has increased from a standard size of 30 in. to a maximum of 48 in. increase, beyond which it is limited by the size and strength of men; indeed, a 48 in. machine can only be cared for by a big labourer; with increase in size of machine, a decrease in the number of revolutions (but not in the peripheral speed) follows. The smaller machines are run at 1,200 to 1,500 revolutions per minute, and the larger at 800 to 1,000.

Capacity of Machines.—A 30 in. suspended Weston machine will produce from 1,600 to 2,000 lbs. of dry sugar per hour from a typical first masse cuite; a 42 in. machine will produce up to 4,000; masse cuites however, vary so much, even when boiled from syrups of apparently the same composition, and so much depends on the craft skill of the sugar boiler and curers, that estimates of capacity are of little value; this is especially so in the case of low sugars; in addition, the type of sugar made, raw or washed, influences very much the capacity.

Washed Sugars.—The sugars generally made on plantations are shipped to refineries for further treatment and are not washed in the centrifugal basket; in Mauritius and Java, however, large quantities of white ('*plantation refined*') sugars are made for the Indian market and these sugars

are also produced in quantity where a large local demand exists as in Natal and South American countries. The special methods of clarification have been described in Chapter XIII.; in curing these sugars water and then steam are used.

In many factories specializing in these sugars the writer has seen the water thrown into the basket from a saucepan or other simple receptacle. A more efficient scheme is shown in *Fig. 210*; the water leaves the nozzle in a fine spray and is evenly distributed over the sugar; the pipe is jointed at *b* so that the part *b c* may be swung out of the basket during charging. After
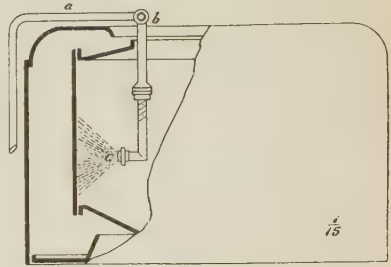
FIG. 210.

the water has been used, steam is admitted to the interior of the basket. In Mauritius steam at 60 lbs. per square inch pressure is led to the basket from the main steam pipe by means of a flexible hose; the action of the steam is two-fold; the elevation of temperature makes the molasses more limpid, and condensation of the steam and water already present dissolves out some crystal sugar. Superheated dry steam does not dissolve sugar, and hot air would have the the same effect, but some solution and temporary loss of sugar is necessary so as to entirely remove the film of molasses and to obtain a really high class article; actually a massecuite which would give say 64 per cent. of raw sugar will give 50 per cent. of plantation refined. The sugar thus obtained remains in the basket as a hard compact mass and before bagging has to pass through a sugar breaker or mixer; dry sugar 'polarizing 99·7' at 28° C. may be obtained with this scheme.

Classification of Syrups.—When sugars are washed the last runnings are of high purity and should be collected separately. One method consists of the use of two gutters as shown in *Fig. 211*; when the molasses
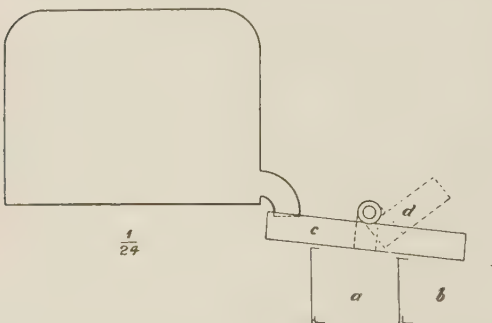
FIG. 211.

proper is running it is directed to gutter *b*, the spout *c* being in the position shown; when water or steam are being used the spout *c* is raised so as to occupy the position shown by the dotted lines and the runnings pass into the gutter *a*. Owing to the slowness with which molasses flow, only a very partial separation occurs.

A large number of devices to obtain the separation of a rich and poor molasses have been patented ; the main idea is the interposition between the outer monitor casing and the wall of the basket of a partition removable at will ; when the effluent from the basket impinges on the partition it passes to one gutter, and when the partition is removed the effluent strikes the monitor casing and passes to a second gutter.

Patterson's apparatus, which is but one of many recent inventions to this end, is shown in *Fig. 212.* It consists of two cones attached to the basket, top and bottom, so that their bases nearly meet in the centre. These cones A A deliver the molasses from the annular opening F, and not all over the casing like an ordinary centrifugal basket. Besides the usual gutter in the bottom, another narrow and deep gutter H is placed inside the casing for the
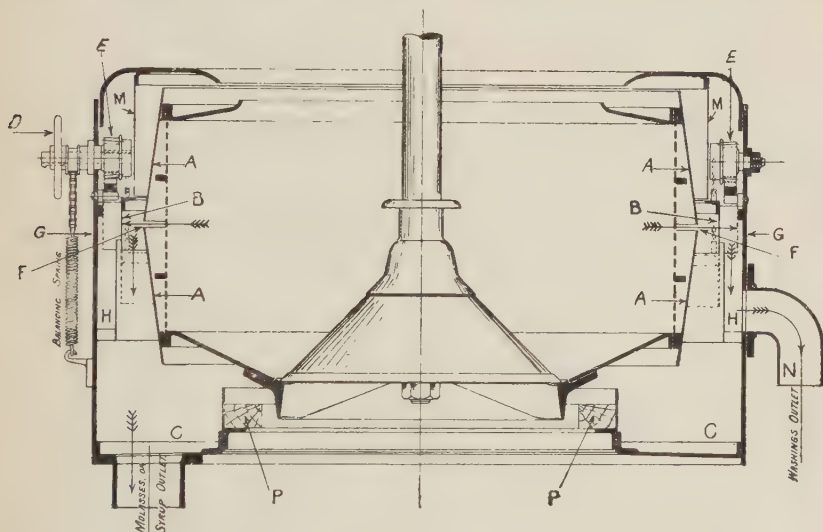
Fig. 212.

washings ; its top being below the level of the annular opening formed by the cones. A movable guard B suspended by four chains from an equal number of pulleys E controlled by a hand wheel D on the outside, hangs between the basket and the washings gutter. The weight of the movable guard is balanced by a spring attached to the hand wheel. Thick copper wire cloth suspended over the washings gutter prevents splashing; the fixed guard M protects the gearing from 'spill,' and the blocks P secure the apparatus in case of excessive oscillation.

The centrifugal is charged and spun with the movable guard raised, as shown in *Fig. 212.* The molasses, caught on the cones attached to the basket, are at once discharged by the centrifugal force and conducted by the movable guard to the usual gutter in the bottom, leaving the cone surfaces clean and ready for immediate washing. When washing commences, the guard is

lowered by the hand wheel out of range of the annulus, the washings are caught on the wire cloth and conducted out of the centrifugal by the special gutter.

Another very complete but expensive process consists in the use of two sets of centrifugals in one of which the original molasses are removed; the sugar is discharged, repugged with syrup, and again cured with water and steam washings; the second purgings return to first sugar manufacture and the first purgings are treated separately.
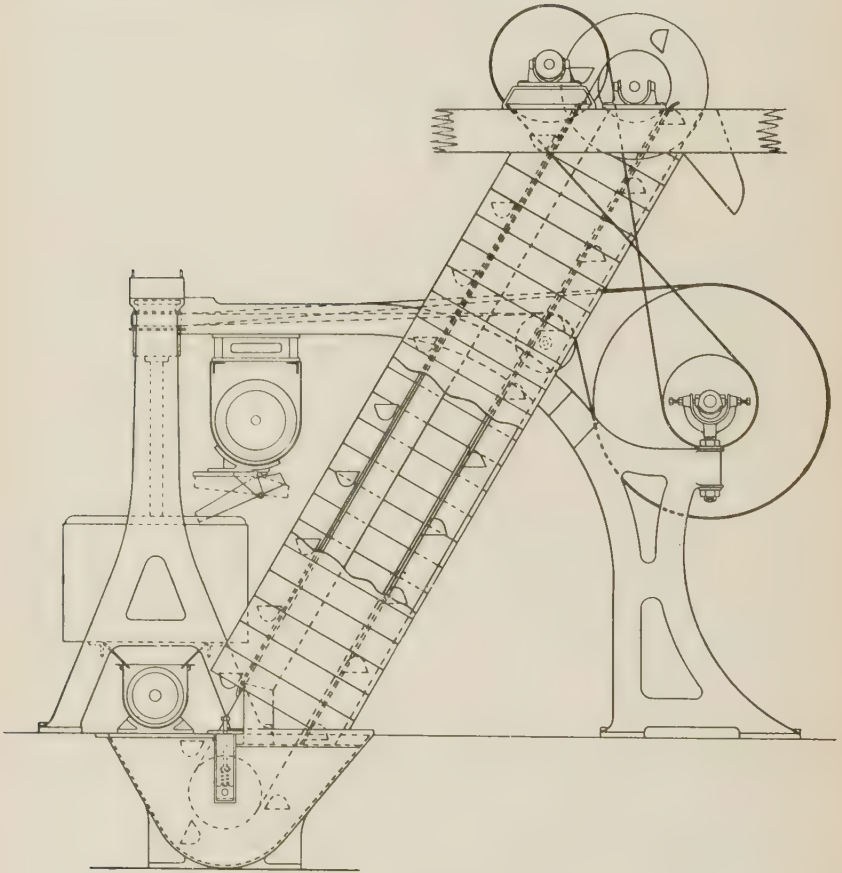
FIG. 213.

Conveyance of Cured Sugar.—In some instances the cured sugar is filled into bags directly from the baskets; but in the majority of cases it is elevated to an upper floor of the factory, whence it is, after becoming partly air dried, directed down shoots into the bags in which it is packed.

The elevator in most common use is shown in *Fig. 213;* it consists of an endless belt carrying a number of buckets; the belt can be arranged to work at any angle; the dry sugar is carried on one of the systems described below to the elevator, and falls directly into the buckets.

The transport of the sugar from the centrifugals to the elevator is effected by means of a belt, a '*grasshopper*,' or a spiral conveyor. Belt conveyors, which are but little used, consist merely of endless belts running on pulleys. The grasshopper conveyor, *Fig. 214*, is a suspended trough supported
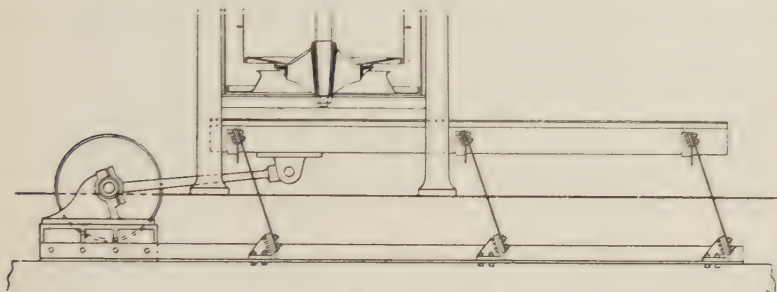
FIG. 214.

on flexible inclined blades; a to and fro motion is transmitted to the trough by means of a belt, pulley and connecting rod, whereby the sugar is jerked forward. The spiral conveyor, *Fig. 215*, consists of a trough in which rotates a steel spiral, the sugar being carried forward by the action of this screw. Of these systems, the writer prefers the grasshopper, as in the screw conveyors a certain loss occurs, due to crushing of the grains from the action of the screw.

Where the sugar is bagged directly from the basket, the bags are carried to the storage room on an endless slat conveyor.

Storage of Sugars.—It is often necessary to store sugars for long periods, whereby deterioration sometimes occurs; the evidence connecting deterioration with bacterial action is collated in Chapter XXVI. It may be said that two postulates are necessary for deterioration, sufficient moisture and presence of bacteria. Deerr and Norris[2] found that with 1 per cent. of water
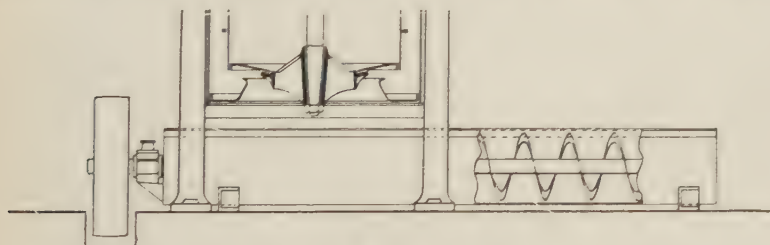
FIG. 215.

infected sugars did not suffer deterioration; a '*factor of safety*' due to the Colonial Sugar Refining Co. of Australia, and which has become widely known, is that the water should not be more than half the non-sugar, or when

$$\frac{\text{water}}{100 - \text{polarization}} < \cdot 333,$$ the sugar will not deteriorate.

Although sugars may be dry on storing, they may take up water afterwards and in the presence of bacteria suffer loss. This deliquescence is due entirely to the film of molasses and is connected with the following causes; to the presence of hygroscopic salts such as acetates occurring when stale or damaged or diseased canes are worked up or when an excess of lime has been used in the presence of much glucose; to the presence of chlorides introduced from the soil or irrigation water, as was noticed by Wray so long ago as 1848; to decomposition products formed by overheating.

Protection of the sugars can be partially obtained by the construction of a close and tight warehouse, and the use of an interior proof paper bag is also recommended in some quarters.

In beet sugar districts stress is laid on packing the sugars only after thorough cooling and on an alkaline reaction; this last cause cannot affect cane sugars since they are almost invariably acid as regards phenolphthalein.
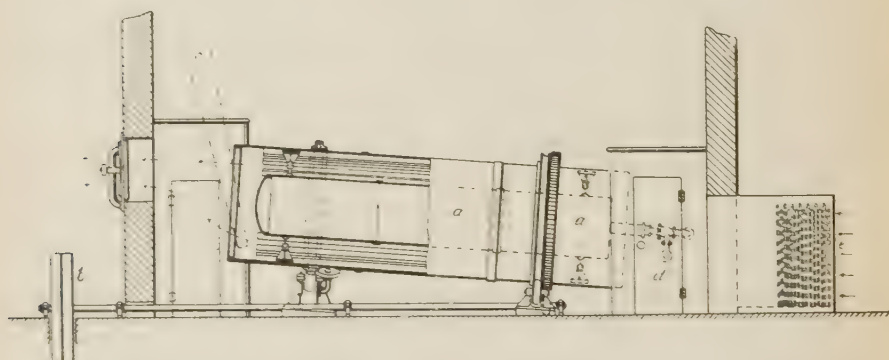
FIG. 216.

Infection of Sugars.—The studies of Lewton-Brain and Deerr[3] on Hawaiian sugars showed that the forms of bacteria met with are heat resistant and are not destroyed in the usual process of manufacture; hence a juice originally infected will afford an infected sugar; the possibility of obtaining sterile syrups, &c., is one of the points (in the writer's opinion) in favour of the use of superheat clarification. There are many other points of infection, of which the most prominent are the return of low grade sugars obtained from exposed coolers, and the use of dirty water at or about the centrifugals; the tin pail so often seen as a receptacle for water, into which a filthy rag is dipped which then serves to wipe down the spindle and about the machine, is a source of infection which may result in serious deterioration. Here of all places absolute asepsis should be aimed at, an end approximately obtained by the use of condensed water continually renewed and not allowed to stand, combined with the application of formalin as a bactericide.

Sugar Driers.—Sugar driers are used to dry white plantation refined sugars and also find a use in drying the rather low grade sugars resulting from crystallization in motion schemes. A view of a form of drier is shown in *Fig. 216*; it consists of an inclined cylinder *a a* which is caused to revolve about a longitudinal axis, power being received from a belt at the pulleys *b*; inside the cylinder are a number of shelves which throw the sugar about in passage; the wet sugar enters through the shoot *c* and leaves at *d*; hot air heated by passing over the steam heated coils at *e* passes through the cylinder and leaves at *f* under the influence of a fan. In the Hawaiian islands the sugar occupies about five minutes in its passage through the apparatus and reaches a temperature of about 180° F., the moisture falling from about 1·5 per cent. to about ·5 per cent.

Druelle Say Process.[4]—However carefully the massecuite is boiled, a certain amount of fine grain is formed which passes through the centrifugal mesh; this process aims at recovering this loss through the agency of filtration; the molasses containing the fine grain are passed through filter presses of conventional design, the cake of fine grain which forms in the presses being dissolved in the thin juice.

Experimental Study of Centrifugals.—The various questions that arise with regard to the treatment of massecuite in the centrifugal have been carefully studied by Geerligs[5]. He determined first from actual factory experiments the yield in the same massecuite when boiled to different degrees of concentration and found that although more sugar separates out in close boiled than in more open boiled massecuite, the yield in crystals is not augmented, as more water is required to remove the more viscid molasses; on the other hand, there is a limit to the amount of water which should be left; he found the best results were obtained when the true water content was 8 per cent. to 9 per cent., corresponding to an apparent water content of 5 per cent. to 7 per cent.

He found too, that when impure massecuites were cured hot, direct from the pan, practically the same amount of crystals was obtained as when cured cold, but that with pure massecuites considerably more crystals were obtained when cured cold. This result is of course due to the sugar in the impure massecuite, when cooling, separating as small grain; in the pure massecuite of less viscidity, to the sugar separating on grain already present.

As a general rule the amount of sugar present as crystals is very much the same in all first massecuites of both high and low polarization, and it is the form and shape of the crystals that control the yield in the centrifugal. This point is of such interest that the following table due to Geerligs is reproduced here, where it will be plainly seen on inspection that the purer

massecuites gave a larger yield, not because more sugar was present as crystals, but because a larger proportion of the crystals were recovered.

Polariz-ation.	Glucose.	Water.	Quotient of Purity.	Crystal-lized Sugar.	Sugar in the Syrup.	Crystals obtained	Crystals lost.	Sugar obtained.
	Per cent.	Per cent.						
74·1	11·07	9·02	78·06	61·62	12·48	51·1	10·11	54·8
78·9	8·99	7·76	83·58	68·22	10·68	58·81	9·41	64·3
79·0	8·47	7·82	83·72	69·09	9·91	55·28	13·81	58·8
81·1	6·93	9·2	87·23	66·96	14·14	60·0	6·96	62·85
84·1	4·81	8·11	88·62	67·81	16·29	64·1	3·71	66·1
84·2	3·20	9·77	90·28	64·13	20·07	62·01	2·12	67·5
84·8	2·74	8·23	88·93	62·93	21·87	59·46	3·47	3·40
86·7	1·83	7·58	93·45	67·10	19·60	66·80	0·30	74·1

That the size of the crystals has much to do with the removal of molasses is self-evident, when it is remembered that the larger the grain the less is the area of contact for the molasses, and consequently the latter are the more easily removed; Geerligs demonstrated this by allowing syrup to drain from massecuites in which the size of the grain varied; his results are given below:—

		m.m.	Syrup run off; grms.
Diameter of the grain	.. ..	3·0	.. 300
,,	,, ...	2·0	.. 265
,,	,, ...	1·5	.. 200
,,	,, ...	1·0	.. 115
,,	,, ...	0·5	.. 20

Mixtures of 600 grms. sugar crystals and 400 grms. of syrup, as indicated above, were allowed to drain for three days, the larger the diameter of the crystals the greater the quantity of syrup run off.

This experiment has however a double interpretation, for the rate at which a syrup is desaccharified depends on the area of crystal surface in contact with molasses, so that apart from questions of purging, a small grain and large surface is often required; the processes followed and kind of sugar produced are the factors which control the size of crystal to be made.

The general rules for the treatment of massecuites may then be summarized. Impure massecuites with purity under, say, 80-81, give best results when not boiled too close and when cured hot; purer massecuites may be boiled to a less water content and should be cured cold; as even a grain as possible should be made. This is a point where the skill of the pan boiler is shown, and is really of very great importance; a juice which, in the hands of one pan boiler, gives a massecuite from which 56 per cent. to 58 per cent. of crystals are recovered may, when boiled by one more skilful, give a recovery of 60 per cent. to 62 per cent.

Composition of Sugars.—The isolated examples of analyses often found quoted in text books are of little interest, as not necessarily denoting the average of the district whence they come.

The figures published by the Java Experiment Station would indicate an average content of over 97 per cent. in the refining grades ; the per cent. of water is not stated. Hawaiian sugars are of similar polarization and contain about ·8 per cent. water. Similar sugars are doubtless made in other progressive sugar districts; muscovados or common process sugars are of very variable quality, but about 90 per cent. sugar would be a fair average. Low sugars, *i.e.*, under 95° polarization, have now a very restricted output.

The other bodies present, glucose, ash and organic non-sugar, vary within wide limits ; in refining crystals neither the glucose nor ash often reach 1 per cent., but they amount to 2 per cent. and over in low grades. The plantation refined sugars, produced in quantity in Mauritius and Java and elsewhere, often polarize as high as 99·6 at 30°C., and are hence almost pure ; they contain only traces of ash, glucose, water, and organic non-sugar.

REFERENCES IN CHAPTER XVIII.

1. *I. S. J.*, 98.
2. *Bull*. 21, *Agric. H.S.P.A.*
3. *Bull*. 9, *Path. H.S.P.A.*
4. *I. S. J.*, 99.
5. *S. C.*, 390.

CHAPTER XIX.

MOLASSES.

Geerligs' Theory of Molasses.* — The chief factor in the formation of molasses was formerly considered to be the viscidity of the syrups preventing free movement of the sugar molecules; this theory fitted in with the knowledge that in beet molasses the sugar content was higher than in a saturated aqueous solution containing the same amount of water; in cane molasses the reverse is generally the case. This observation is alone sufficient to invalidate the older theory, known as the mechanical theory of the formation of the molasses. The whole subject has been the object of a classical research by Geerligs[1].

Geerligs introduces his subject by a discussion of the methods of analysis of molasses, and shows—

1. The method of direct polarization gives results that may be too high or too low.

2. Clerget's method gives results agreeable with those obtained by determinations of glucose before and after inversion.

3. The glucose present has a lower levo-rotation than that due to pure invert sugar.

4. The glucose present is not inactive at 88° C., the temperature at which the activity of invert sugar vanishes.

Of earlier experimenters Gerard and Laborde[2] and also Müntz and Hulze[3] found glucose from cane sugar inactive; Gunning[4] and Meissl[5] found the rotation of glucose in cane molasses the same as for invert sugar.

Herzfeld[6] and Wehne[7] found the glucose to consist of varying quantities of dextrose and levulose. The last result is the one to which Geerligs came; in his results it is always the dextrose which is present in the greater proportion, and accordingly it is quite possible for the mixture to be optically inactive. After having made complete analyses of a number of molasses,

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* When "Sugar and the Sugar Cane" was published, Geerligs' theory was only to be found described in journals; since then he has detailed his theory in his treatise 'Cane Sugar and its Manufacture' to which reference may be made for a complete account.

Geerligs reviews the results of earlier investigators.   Marschall[8] determined the effect of the presence of salts that occur in beet molasses on the solubility of sugar; he found that sugar was more soluble in the presence of either acetate, butyrate, carbonate or citrate of potash, but that all other salts had no effect, or diminished the solubility. Felz[9] adhered to the mechanical theory, holding that the viscidity of molasses prevented crystallization; this mechanical theory is not accepted by Geerligs who found that the maximum amount of sugar crystallized out from solutions made thick with glue or agar-agar, the viscosity being much greater than in molasses.

Gunning[4] formed artificial molasses by admixture of pure sugar and solutions of alkaline organic salts; he found that potash salts formed with sugar syrupy combinations which did not crystallize, and deduced the formation of a saccharate of potash; he gave 6·1 as the molasses-forming coefficient of potash, *i.e.*, one part of potash (as KOH) prevents 6·1 parts sugar from crystallizing; for acetate of potash the figure would be 1·5 allowing only half the potash to affect the sugar, the other portion remaining as an acid salt.

It had been previously stated by nearly all writers that glucose was melassigenic; the coefficient had been placed by Pellet[10] at 0·60, by Flourens[11] at between 0·30 and 1·0, Degener[12] declaring that glucose had no direct melassigenic property but that the acid products of its decomposition inverted sugar. Geerligs made a series of experiments to test this statement. As a source of glucose he used honey in which the dextrose and levulose are present in about the same proportion as in molasses; he thus was able to prepare a series of solutions in which the water and sugar were constant but the glucose varied from nothing up to 25 grms.; the sugar present was always 25 grms. and the water 7·5 grms. It was found that the sugar crystallizing out was always the same and that the glucose had no effect and hence was not melassigenic. Geerligs next tried the effect of the presence of acetate of potash and the combined effect of this salt and glucose; he found that one part of acetate of potash per 25 of sugar had no effect, with two parts the effect was noticeable, and was very marked with five parts; but when one part acetate of potash and ten parts glucose were present per 25 parts sugar the combined effect was anti-melassigenic, *i.e.*, more sugar crystallized out than from water alone, and it was not till five parts acetate of potash and ten parts glucose were present that the combined effect was melassigenic. In later papers on the subject Geerligs returns to the effect of glucose on the crystalliza- tion of sugar and suggests that glucose forms with organic potassium salts easily soluble syrupy bodies which absorb water and render the proportion of sugar to water lower than normal; this point is entirely supported by his analyses when the ratio of glucose to alkalinity of the ash as potash is considered, the alkalinity of the ash as potash being a measure of the organic salts present, such a salt as acetate of potash giving on incineration carbonate

of potash. As a general and well-marked rule, Geerligs found that when the ratio of glucose to alkalinity is low, *i.e.*, when there is much glucose and little alkalinity, the solubility of sugar in molasses is greater than when the reverse is the case. A further point brought out by the analyses is that when a large proportion of undetermined constituents occurred the solubility of the sugar was low, the undetermined bodies being probably substances of similar constitution to glucose and acting in the same way.

To further test the results found on a study of natural molasses Geerligs formed artificial molasses out of sugar, purified honey and various salts; the salts employed were the acetates of potash, soda and lime, the apoglucinates* of the same bases, inorganic salts such as the chlorides and sulphates, and mixtures of organic and inorganic salts. The method of experiment was that the calculated quantities of sugar, honey, salt and water were put into large flasks, sterilized at 100° C., plugged with cotton wool and allowed to crystallize. The following results were obtained: solutions with acetates only produced no inversion, those with apoglucinates produced little inversion; solutions with inorganic salts always inverted and the inversion was greatest when the quantity of glucose was greatest†; when organic salts and inorganic salts were present the inversion was much less than in the immediately preceding case. The results already obtained with regard to the solubility of sugar in the presence of other bodies were completely confirmed and in addition it was found that the sugar-precipitating power of the organic salts was greatest in the order lime, potash, soda.

The inversion of sugar by the combined effect of glucose and salts was then investigated; it was found that glucose *per se* had no inverting effect but that in the presence of salts, organic or otherwise, it had. Geerligs explains these experimental phenomena in these words, ' . . . *the entire action of molasses forming is explained by the assumption that both sugar and glucose, and those products of decomposition of the latter which resemble caramel, have a tendency to combine with the bases of the salts, and hence to a certain extent act as acids.*' This statement is in entire accord with the theories of Van't Hoff expressed symbolically as

$$\text{Glucose} + \text{Salt} \rightleftarrows \text{Glucosate} + \text{Acid}$$

i.e., if glucose and salt occur together in solution they are mutually to a certain extent dissociated; the same equation holds equally for saccharose.

In accordance with this equation, if saccharose and an organic salt are present together, they are both to a certain extent dissociated, and the saccharose forms with the base a very soluble hygroscopic compound, and hence is explained the abnormal solubility of sugar in beet molasses, which contain but little glucose. When glucose is present along with saccharose, the glucose

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* The decomposition products formed on heating glucose with lime.
† cf. Article 'Inversion,' in Chapter XIII.

possessing an aldehyde group is more readily split up, and forms with the bases similar compounds to the above, and extracting water has the effect of lowering the solubility of saccharose, as is the case in cane molasses. When the carbonatation process is used the glucose is in great part destroyed, and saccharose is found more soluble in carbonatation than in defecation molasses. When glucose and an organic salt are present their mutual dissociation forms free acid and causes inversion, but the inverting power of organic acids being small the inversion is not great. When glucose and an inorganic salt are present the same reaction occurs, and the inversion is greater for the reverse reason.

When glucose, organic and inorganic salts are present, the combined effect is chiefly that due to the organic salt, and the effect of the inorganic salt is modified.

The causes tending towards the formation of molasses may be summarized—

1. The presence of non-sugar requiring water for its removal, such water carrying away sugar.

2. The formation of molecular compounds consisting of sugar and organic salts, chiefly potash salts.

3. Inversion under the influence of acids as when working with phosphoric acid and under the combined influence of glucose and salts, chiefly inorganic salts.

4. An excess of lime acting on glucose, originally present and giving rise to organic salts, which then act as in (2) and (3).

5. Viscosity of syrups resulting in formation of fine grain which passes through the centrifugal.

6. Careless pan boiling, resulting in fine grain, requiring much water in the centrifugals.

As tending to prevent the formation of molasses Geerligs indicates but does not recommend the use of baryta, inclining more to the carbonation process, and when the usual defecation process is used he recommends one to—

1. Use as little lime as possible in defecation but of course enough to get a good clarification.

2. Prevent by rapid working and cleanliness every source of acidity, because if juices get sour they require fresh quantities of lime to neutralize the acid and therefore fresh quantities of salts are produced.

3. If any excess of lime has been used, remove it by the use of phosphoric or sulphurous acids which decompose some of the organic acids and precipitate the lime.

4. Extract the salts from the after-products by putting the latter under water.

The decomposition of glucose in the carbonation process gives rise to large quantities of organic salts and hence in carbonation molasses the sugar solubility is high; this is counterbalanced by the less quantity of molasses formed.

In later papers on the same subject Geerligs[13] defines molasses as—"a hydrated combination between sugars and salts, which can not be broken up by evaporation, and therefore cannot give off sugar in a crystallized form." He regards the proportion of sugar in molasses as controlled chiefly by the reducing sugars present and writes—"There is no question of the solubility of sucrose at all, but only of the composition of a combination which contains on an average 55 per cent. sugar, 25 per cent. salts, and 20 per cent. water. If there is a big proportion of reducing sugar in that portion of 55 per cent., then there is little left for the sucrose; if on the contrary the percentage of glucose is small, the syrupy combination contains much sucrose.

"It is evident that in my theory there is no place left for negative molasses-formers; the non-sugars, especially salts, combine with sugars and it depends entirely on the mutual relation of sucrose and reducing sugars whether much or little reducing sugars will enter into the combination."

Hawaiian Molasses.—Peck[14] examined a number of Hawaiian molasses and did not find any relation to obtain between glucose and ash; he observed however that molasses containing much sucrose also contained much gum. By gum Peck means the residue obtained after breaking up the lead precipitate by hydrogen sulphide, filtering off the precipitate of lead sulphide and evaporating the filtrate to dryness; he showed that molasses purified by precipitation of the gums with alcohol on concentration afforded a notable crop of crystals. It does not follow that the bodies precipitated by lead and by alcohol are the same, and indeed Hazewinkel[17] has shown that the lead precipitate consists largely of organic lead salts, so that much lead precipitate implies also much organic acid and hence in Geerligs' theory a high solubility of sucrose; further along with the gums precipitated by alcohol much ash also comes down and the crystallization of sugar may have been due (in part at least) to the removal of the ash.

Composition of Molasses.—The only detailed series of analyses of molasses according to district of origin with which the writer is acquainted are those due to Geerligs in Java and to Peck in Hawaii; between these there does not appear much difference and in a very rough way molasses may be regarded as a material containing about 20 per cent. water, 30 per cent. sugar and very variable quantities of reducing sugars, ash, organic acids, caramel and

gums. The composition of the molasses is of course controlled by the initial composition of the juice and this point, as regards the sugar content of the molasses, is discussed in greater detail below. Actually the limits of the composition of molasses may be put down as

Water 15 per cent.—25 per cent.; total solids 75 per cent.—85 per cent.; sucrose 25 per cent.—40 per cent.; reducing sugars 5 per cent.—30 per cent.; ash 7 per cent.—15 per cent.; gums 5 per cent.—3 per cent.; organic non-sugar 10 per cent.—20 per cent.; purity 35 to 50.

The lower amounts of reducing sugars are found in the Hawaiian Islands where the juices are exceptionally pure and contain very little reducing sugars in the juices, sometimes as low as ·2 per cent.; the higher amounts are found in Louisiana and Demerara molasses where the reducing sugars in the juices may rise to 2 per cent. or more; other districts will have intermediate quantities.

Exceptionally low purities of 20 or under are sometimes reported in Louisiana, but Browne,[15] who has had exceptional opportunity to examine such molasses, has stated that these are due to inversion or to errors of analysis.

The Bearing of Glucose on the Sucrose Content of Molasses.—In constructing his theory of molasses Geerligs made certain experiments the results of which, he thus summarizes, " . . . show that glucose of itself possesses no molasses-forming power, nor can it serve to make more sugar crystallize out." Accepting, then, that glucose is an indifferent body its effect on molasses can be algebraically developed as under. Molasses of whatever origin are of composition, water 20 per cent., solids 80 per cent.; a typical beet sugar molasses obtained in the absence of glucose is of composition, sugar 45 per cent., solids not sugar 35 per cent., water 20 per cent.; to such a molasses let 20 parts of an indifferent body, such as glucose, be added; the mixture will now be of Brix $(80 \times 20) \div 120 = 83 \cdot 33$; let x be the amount of water to be added to reduce the Brix to 80; then $\dfrac{20 + x}{120 + x} = \cdot2$; whence $x = 5$. The new formed mixture will, when reduced to 80° Brix, be of composition, sugar 36 per cent., glucose 16 per cent., non-sugars 28 per cent., water 20 per cent., purity 45; such a composition is that of a typical cane molasses. Proceeding on this argument the following table of the composition of molasses is capable of construction, beet molasses of the composition given above being taken as a basis of calculation; to this molasses quantities of glucose 3, 5, 7 &c., per 100 original molasses being added, and the composition of the mixture being then calculated back to 80° Brix.

Glucose added per 100 original molasses	Sugar per cent.	Glucose per cent.	Non-sugars per cent.	Water per cent.	Sugars per cent.	Purity.	Glucose, Non-sugars.
0	45·0	0	35·0	20·0	45·0	56·2	0
3	43·4	2·9	33·7	20·0	46·3	54·2	·08
5	42·3	4·7	32·9	20·0	47·0	52·9	·14
7	41·4	6·4	32·2	20·0	47·8	51·7	·20
10	40·0	9·0	31·0	20·0	49·0	50·0	·29
12	39·1	10·4	30·4	20·0	49·5	48·9	·34
14	38·3	11·9	29·8	20·0	50·2	47·9	·40
16	37·4	13·3	29·3	20·0	51·1	46·7	·46
18	36·7	14·7	28·6	20·0	51·4	45·9	·51
20	36·0	16·0	28·0	20·0	52·0	45·0	·58
24	34·6	18·4	26·9	20·0	53·0	43·2	·68
28	33·3	20·7	25·9	20·0	54·0	41·6	·80
32	32·1	22·9	25·0	20·0	55·0	40·1	·92
36	31·0	24·8	24·1	20·0	55·8	38·9	1·03
40	30·0	26·7	23·3	20·0	56·7	37·5	1·14
44	29·0	28·3	22·6	20·0	57·3	36·2	1·25
48	28·1	30·0	21·9	20·0	58·1	35·1	1·37
52	27·2	31·5	21·2	20·0	58·7	34·0	1·48
56	26·1	32·9	20·2	20·0	59·7	32·6	1·66
64	25·0	35·5	19·4	20·0	60·5	31·2	1·83
72	23·7	37·9	18·4	20·0	61·6	29·6	2·06
80	22·5	40·0	17·5	20·0	62·5	28·1	2·28
88	21·4	41·9	16·7	20·0	63·3	26·7	2·50
96	20·5	43·6	15·9	20·0	64·1	25·6	2·74

The Addition of Glucose not a Precipitant of Cane Sugar.

—The idea has unfortunately come about in many quarters that Geerligs' theory of molasses implies that the addition of glucose will cause sugar to crystallize; there is no ground for this deduction anywhere in his theory. High glucose certainly implies a low purity in molasses but at the same time the addition of glucose will lower the initial purity of the juice; the fallacy of this deduction can be best shown by an actual example.

Following on the previous sections a juice containing 14 per cent. sugar, 2 per cent. non-sugar and no glucose will give a molasses of 56·2 purity; the initial purity of the juice is 87·5; applying the formula for available sugar (Chapter XXV.) in its simplest form, namely, extraction $= \dfrac{j - m}{j\,(1 - m)}$, the sugar to be obtained is 81·6 per cent. Now to this juice let one part of glucose be added; the juice will now be of purity 82·35 and molasses of purity 47·50 may be expected; the extraction will now be 80·6 per cent., a lower result than obtained before the addition of the glucose.

If, however, instead of glucose solids not sugar be added, a purity of 56·2 may be expected and with initial purity of 82·35 an extraction of 72·5 will result.

This calculation goes to show that of all the impurities present in a cane juice the glucose is the least harmful, but that its addition lowers the possible recovery.

Geerligs' theory has even been distorted as implying that inversion of part of the sugar would increase the yield; it is hard to see how such a meaning could be read into it.

The Glucose : Non-Sugar Ratio.—According to the position taken up by the writer, the purity of the waste molasses is controlled by the glucose : non-sugar ratio, and as the proportion of glucose increases so also does the total sum of the sucrose and glucose. With beet sugar molasses where glucose is not present, the sucrose amounts to about 45 per cent. and such a condition is sometimes found approximately in the Hawaiian Islands : where as often happens, in Java for example, the glucose or non-sugar are in approximately equal proportions, the sum of the sucrose and glucose amounts to about 55, a figure which may rise to 60 and over in the juices resulting from extra tropical canes found in Louisiana and from sea level equatorial canes as found in Demerara. No absolute concordance can be expected, as the effect of the nature of the non-sugar is very great; concurrently, as shown in Geerligs' theory, with the presence of much organic potassium salts a high purity is to be expected; this observation is in line with Peck's analyses where he found much lead precipitate correlated with a high purity since Hazewinkel[17] has shown that the lead precipitate consists largely of organic salts.

The following table of analyses of Hawaiian molasses by Peck and Deerr wherein all the analyses are calculated to a water content of 20 per cent. does *not* show the regularity to be expected from the above line of reasoning. Certainly with high glucose the sum total of the sugars tends to increase but the purities do not correspond, and indeed the last three analyses quoted, where a high purity might be expected due to the low glucose, have purities below the average. The nature of the solids not sugars probably exercises a big

influence, although when these are kept constant as already shown a fair agreement follows; all that can be said is that a high initial glucose nonsugar ratio probably will result in molasses of low purity, the reverse also holding.

Viscosity as affecting Molasses Formation.—Geerligs found that sugar crystallization was the same in a medium thickened with agar-agar; viscosity, however, tends towards sugar losses, as in viscous media the crystals formed are small and to obtain free purging a lower concentration is required; these causes are really outside the matters discussed above which refer to a saturated molasses free from fine grain.

Recovery of Sugar from Molasses.—So far as the writer is aware the schemes used to some extent in beet sugar factories are not employed in cane sugar factories; they are, however, touched on below.

Sugar.	Glucose.	Non-Sugar.	Water.	Sugar and Glucose.	Purity.	Glucose : Non-Sugar.
36·6	22·9	20·5	20·0	59·5	45·7	1·12
31·5	17·9	30·8	20·0	59·2	38·9	·58
41·1	14·8	24·1	20·0	55·9	51·1	·61
40·3	15·4	24·3	20·0	55·7	50·4	·63
42·3	13·3	24·4	20·0	55·6	52·9	·54
34·5	20·8	24·7	20·0	55·3	43·2	·84
35·1	19·9	25·0	20·0	55·0	43·9	·79
37·0	17·4	25·6	20·0	54·4	46·2	·68
39·2	14·7	26·1	20·0	53·9	49·6	·56
36·6	16·9	26·5	20·0	53·5	45·7	·63
35·3	18·0	26·7	20·0	53·3	44·1	·67
43·9	6·8	29·3	20·0	50·7	54·9	·23
35·2	15·0	29·8	20·0	50·2	43·9	·61
32·6	17·4	30·0	20·0	50·0	40·7	·58
35·8	13·6	30·6	20·0	49·4	44·7	·44
34·6	14·3	31·1	20·0	48·9	43·2	·46
38·4	10·4	31·2	20·0	48·8	45·5	·33
35·5	13·0	31·5	20·0	48·5	44·4	·41
41·7	6·4	31·9	20·0	48·1	52·1	·20
37·2	9·1	33·7	20·0	46·3	46·3	·27
37·4	8·9	33·7	20·0	46·3	46·7	·26
33·7	11·2	35·1	20·0	44·9	42·1	·32
37·4	16·8	25·8	20·0	44·2	46·7	·65
32·3	10·9	36·8	20·0	43·2	40·4	·30
36·9	6·2	36·9	20·0	43·1	46·1	·17
34·9	7·2	38·9	20·0	42·1	43·6	·19
32·3	8·8	38·9	20·0	41·1	40·4	·23

Osmosis.—It follows from the above sections that if the salts could be removed from an exhausted molasses, the conditions of solubility of the sugar would be altered and a further portion would be capable of crystallization. About 1850 a method of effecting this was worked out by Dubrunfaut. The principle of his process known as *osmosis* is as follows : If a concentrated solution of any soluble body be separated from a weaker solution or from water by a semi-porous membrane, such as parchment, the two solutions will pass through the membrane until they are of the same concentration. The rate at which this osmosis or diffusion takes place is not the same for all bodies ; inorganic salts such as potassium chloride diffuse much faster than sugar ; hence if a solution of molasses be separated by a parchment membrane from water, a greater proportion of salts will pass through the membrane in a given time than sugar. An osmogene is an apparatus to effect this separation ; it consists of a structure similar to a filter press in which are held a series of wooden frames, shown in elevation in *Fig. 217.* Between each frame are placed sheets of
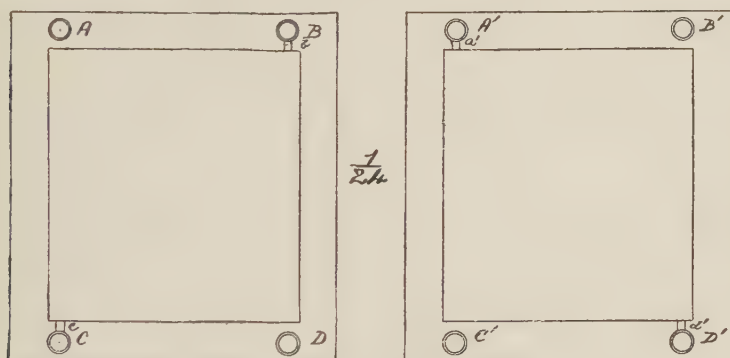
Fig. 217.

parchmentized paper, pierced at the angles to correspond with the apertures shewn at A, B, C, D, and at A', B', C', D', in *Fig. 217.* At *b* and *c* in the one frame, and at *a* and *d* in the other, are small channels establishing communication with the interior of the frame. If, then, water enters at B and molasses at D, the water will flow along the canal formed by the openings B and into the interior of the frames by the channels *b*, and the molasses will similarly flow by way of D and *d'*. The water will discharge itself along the canal formed by the openings C and *c*, and the molasses along that formed by the openings A' and *a'*. There is thus a continual flow of molasses and water separated by a sheet of parchment. The water which leaves the apparatus now charged with a proportion of molasses is called water of exosmose, and it contains roughly about half the salts originally present in the molasses. Although this process has been largely used in times past and is still to a certain extent employed in beet sugar factories it is financially unsuccessful ; the large size of the osmogenes required (500 square feet diffusion surface only

being sufficient to treat three tons of molasses in twenty-four hours), the extreme dilution of the osmosed molasses, the expense of evaporation, and the small extra yield of sugar entirely discounting the monetary value of the process.

Substitution Processes.—The Steffen and Scheibler substitution processes although they are not worked in cane sugar factories deserve a passing notice. With bases cane sugar acts as a weak acid and forms saccharates, those of potassium, lime, strontia, baryta, lead and iron having been studied. With baryta only one saccharate is known:—$C_{12}H_{22}O_{11}BaO$; it is formed as a crystalline precipitate when a mixture of a solution of baryta and sugar is heated; it dissolves in 41 parts of water at 15° C.

With strontia two saccharates are formed; on mixing two molecular proportions of strontia with one of sugar in a boiling solution the bibasic saccharate

$$C_{12}H_{22}O_{11}2SrO.$$
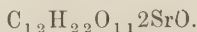
results and on cooling this body decomposes into the monobasic saccharate

$$C_{12}H_{22}O_{11}SrO$$
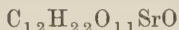
and strontia.

With lime, four saccharates are formed; the monobasic saccharate

$$C_{12}H_{22}O_{11}CaOH_2O$$
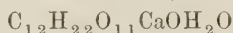
is formed by mixing molecular proportions of lime and sugar. This body is soluble in the cold, and is precipitated from aqueous solution by alcohol.

The bibasic saccharate

$$C_{12}H_{22}O_{11}2CaO$$

is formed by mixing a double molecular proportion of lime with one of sugar. It is soluble in 33 times its weight of cold water.

The sesquisaccharate

$$2C_{12}H_{22}O_{11}3CaO$$
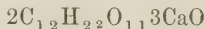
is obtained by pouring an excess of milk of lime into a dilute solution of sugar and evaporating to dryness.

If a solution of the bibasic saccharate be boiled it is decomposed, giving the tribasic saccharate

$$C_{12}H_{22}O_{11}3CaO,$$
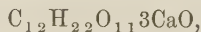
sugar and the bibasic form.

On these reactions are based the commercial processes for the extraction of sugar from exhausted molasses.

The first processes were those of Scheibler (1865) and Seyferth (1872). In them molasses and slaked or quicklime were intimately mixed in a pug mill, and the resulting magma of saccharate and molasses washed with alcohol to remove the salts and organic non-sugar, and the purified saccharate mixed with the juice and carbonated. Many mechanical improvements were introduced by Bodenbender and Manoury, the former obtaining the saccharate

in the form of cakes and the latter as grains. In both cases denaturated alcohol (duty free) is used, the alcohol being recovered for use. Over 90 per cent. of the sugar in the molasses is extracted at an average cost of 2s. for every 100 lbs. of molasses treated.

The original substitution process of Steffen eliminates the use of alcohol and is based on the behaviour on boiling of the mono- and bibasic lime saccharates. The five operations in the process are : —

1. Formation of a soluble bibasic saccharate in the cold.

2. Transformation of the bibasic saccharate into sugar and insoluble tribasic saccharate by boiling.

3. Separation by filtration of the tribasic saccharate.

4. Regeneration of the mother liquors by the addition of fresh molasses.

5. Periodic reduction of the mother liquors.

In outline the different processes are worked as follows :—

1. Molasses diluted to 11°–12° Balling are mixed with continual agitation with powdered quicklime in the proportion of one part sugar to one of lime ; the mixture is then filtered to remove scums.

2. The filtrate is heated for ten minutes in autoclaves to a temperature of 105°C.

3. The tribasic saccharate formed in (2) is filtered, the cakes washed with boiling water, and the saccharate employed in place of lime in treating the raw juice.

4. The mother liquors coming from (3) are used to dilute a further quantity of molasses to a sugar content of 6 per cent.

5. After a time the mother liquors are so charged with impurities as to render them too impure to return ; they are then treated separately, two operations sufficing to almost completely exhaust them. The mother liquors are returned about 25–30 times, after which the process commences afresh.

The cost of this process is only about 1s. per 100 lbs. of molasses, a recovery of over 90 per cent. of the sugar in molasses being obtained.

The second more recent process of Steffen considerably modifies and simplifies the above process.

It consists of three parts :—

1. Preparation of a very pure finely divided quicklime.

2. Formation of a tribasic saccharate insoluble in the cold.

3. Extraction and purification of the saccharate.

In preparing the quicklime, a very pure non-siliceous limestone is selected which is burned out of contact with the fuel (see Chapter XI) ; the burnt lime is broken up in a stone-breaker and passed through a series of sieves to obtain it in the necessary fine state of sub-division.

In the second operation the molasses diluted to a density of 10°–12° Brix are cooled down to a temperature lying between 0° C. and 13° C., generally to one of 6° C., and quicklime added in small quantities about 10 lbs. at a time until 210 parts of lime are added per 100 of sugar; during the whole operation the molasses are continually agitated and the temperature is not allowed to rise above 13° C.; at the end of the process, which lasts about three-quarters of an hour, there is obtained a pasty mass, consisting of a mixture of tribasic saccharate and slaked lime.

The third operation consists of separating the saccharate by filtration and washing with cold water; the filtrate which contains practically all the impurities is rejected, the washings being used to dilute a further quantity of molasses; the purified saccharate is either used in place of lime on raw juices or is treated separately by carbonation. The cost of working this process is only about half that required for the older Steffen process.

The discovery of large deposits of strontianite in Westphalia opened the way to the use of this material in extracting sugar from molasses.

Two processes both due to Scheibler are in use.

1. *Bibasic Process.*—In this process three equivalents of strontia to one of sugar are added to a hot diluted molasses, and the saccharate which forms is separated from the mother liquors by filtration and washed with a 10 per cent. solution of strontia; all these operations are done when still warm. In order to decompose the saccharate, it is placed in vessels set up in a battery through which is passed water at a temperature of from 4°C. to 15°C., the water containing 2 per cent. of strontia; by these means the bibasic body is decomposed into the monobasic body and strontia; this operation takes about forty-eight hours. A solution of sugar still containing strontia passes out of the diffusers and is treated by carbonation.

2. *Monobasic Process.*—In this process a solution of strontia is mixed with molasses, the temperature not being allowed to rise above 20°C.; the monobasic body formed is separated by filtration and treated to a carbonation process.

The Disposal of Molasses. *By sale as such.*—In certain places the sale of molasses to distillers or for direct consumption forms a part of the routine; in some cases, particularly in the muscovado process followed in Barbados, this procedure is very profitable since fancy prices are still to be obtained for these grades of molasses. Considered from the point of view of the agricultural chemist, nothing can be said in favour of this scheme as it entails the absolute removal from the soil of much valuable plant food, particularly in the form of potash. With the very pure juices found in the Hawaiian Islands the molasses amount to about 20 per cent. of the sugar shipped, a figure rising to as much as 40 per cent. in the case of the impure

juices found in Demerara, and elsewhere; molasses on an average contain about 4 per cent. of potash, so that the sale of the molasses implies the removal from the soil of from 18 to 36 lbs. potash per ton of sugar shipped.

Sale as Cattle Food.—The sale of molasses as cattle food was originated on the large scale by Mr. G. Hughes, who observed that the finely divided interior pith of the cane was capable of absorbing large quantities of molasses, affording a product which could be shipped in bags; this product was put on the market under the name of 'molascuit.'

The manufacture of this article requires plant of a very simple nature, which is generally capable of being placed so as to fit in with existing arrangements. The method of manufacture in a certain West Indian factory is described below. The megass, before the manufacture of molascuit was started, discharged itself from a scraper elevator on to the cross carrier which conveyed the megass in front of the furnaces; a sifter of one-eighth inch mesh and of 8 ft. × 4 ft. dimensions was interposed between the elevator and cross carrier; the megass fell on to this sifter to which an oscillating motion was given by an eccentric driven off a convenient engine; in the passage of the megass along the sifter to the cross carrier a number of the finer particles fell through and these were directed down a shoot on to the flue wall of the boilers. The brickwork on the top of the flue was replaced by sheet-iron plates and a drying surface obtained for the megass; after the megass had been dried it was again sifted through a sifter of mesh one thirty-second of an inch. Refuse molasses was mixed with the doubly sifted megass powder in the proportion of seventy parts of molasses to thirty parts of megass; the molasses were concentrated to 85° Brix before mixing and a much more even product was obtained when hot molasses were used; before bagging, the molascuit was allowed to cool; the mixing was performed in a 'Carter' kneading machine. The double sifting is of importance so as to eliminate the larger particles of megass, especially splinters, consisting of the hard and indigestible outer rind. In other installations more elaborate machinery is employed, and in large plants the use of a drier similar to those used for drying sugar would be advisable both for the megass and for the final product. The keeping qualities of the product depend very largely on the extent to which it is dried.

Molasses feeds are not a complete food and are very deficient in proteid, the percentage of nitrogen being only about ·15 per cent.; hence they require supplementing with other material, especially in the case of working animals. In Mauritius the seeds of an acacia-like shrub, *Lucæna glauca*, are used in combination with molasses, and in Louisiana the ration of molasses is frequently balanced with cotton seed meal. T. U. Walton[18] advises a ration of 15 lbs. of molasses to a 1,270 lb. horse, and states that for working horses this quantity has no undue fattening effect, that the salts in this quantity of molasses are not deleterious, and that sugar is generally an efficient substitute for starch.

The following analyses of molasses feeds are due to Browne[19] :—

	Blood, Cereal. Molasses.		Cotton Seed Meal, Corn, Oats. Molasses.		Corn, Oats. Molasses.		Extracted Rice, Bran. Molasses.		Megass. Molasses.
Water	15·38	..	11·90	..	12·23	..	8·40	..	13·98
Fat	1·11	..	3·15	..	2·30	..	0·83	..	0·90
Ash	9·52	..	6·27	..	7·79	..	9·70	..	5·11
Fibre	12·98	..	14·30	..	12·78	..	13·00	..	5·64
Protein	16·13	..	12·75	..	6·41	..	14·00	..	1·94
Sugars	15·01	..	21·65	..	19·43	..	5·50	..	55·94
Other carbohydrates.	29·87	..	29·98	..	39·06	..	48·56	..	16·49

Manufacture of Alcohol.—In the West Indies and the Argentine generally, and often in Peru, Natal, and Australia, the distillery forms an integral part of the sugar factory, a potable spirit known as rum being manufactured in large quantities. The sale of alcohol leaves all the fertilizing elements in molasses available for return to the soil, and hence this scheme has much in its favour. At the time of writing (1910) the anticipated large production of denatured alcohol from molasses in the U.S.A. has not taken place.

Use as Fuel.—Molasses are occasionally used as fuel to supplement that afforded by the megass; if the ashes are returned to the soil a portion of the plant food is recovered but the nitrogen is lost for immediate use. The fuel value of molasses is discussed in Chapter XX.

Return to Soil.—On irrigated plantations molasses can be returned to the soil at small expense; in Mauritius they are often incorporated with the composts of manure. Ebbels and Fanque[20] have produced evidence that the sugar in the molasses aids the nitrogen-fixing organisms in their work, resulting in an increase in the nitrogen content of the soil, and in increased crops. Their results are extremely suggestive and are a strong argument in favour of this method of disposal, but more evidence is required as to the specific action of sucrose and glucose upon the nitrifying, denitrifying and ammonifying organisms of the soil before the indiscriminate use of molasses can be recommended.

Bonâme[21] has also detailed the results of experiments showing that the effect of molasses is greater than might be expected from its composition; he mentions that in Mauritius a litre of molasses (3 lbs.) is often applied to each cane hole (3000 holes to an acre) and states that this amount might be decreased with advantage so as to spread the available supply over large areas.

On the other hand experiments made by Peck[22] have shown that the continued addition of glucose to soil bacteria *in vitro* retards the activity of the nitrifying and ammonifying organisms and accelerates that of the denitrifying races.

REFERENCES IN CHAPTER XIX.

1. *S. C.* 284-292; 311-313.

2. *Zeits. für Ruben.*, 1876, 399.

3.   ,,   ,,   ,,   1878, 735.

4. *Saccharimetrie in accijns.*

5. *Zeits. für Ruben.*, 1879, 1040.

6.   ,,   ,,   ,,   1885, 967.

7.   ,,   ,,   ,,   1888, 785.

8.   ,,   .,,   ,,   1870, 339; 1871, 97.

9.   ,,   ,,   ,,   1870, 337; 1871, 167.

10.   ,,   ,,   ,,   1879, 806.

11. *Jour. des. Fab. de Sucre*, 1880, 40.

12. *Zeits. für Ruben.*, 1881, 514.

13. *I. S. J.*, 113-114.

14. *Bull.* 18, *Agric. H.S.P.A.*

15. *Bull. Assoc.*, 1897, 1086.

17. *Arch.*, 1908, 53.

18. *H. P. M.*, Sept., 1905.

19. *L. Γ.* xxxiv., 236.

20. *Jour. des. Fab. de Sucre*, 1909, 2.

21. *Annual Report.   Stat. Agron. Mauritius*, 1909.

22. *Bull.* 34, *Agric. H.S.P.A.*

CHAPTER XX.

MEGASS AS FUEL.

The battery of boilers and its connections form one of the most important parts of any factory, and are of peculiar interest in a sugar works, in view of the evaporation produced by the steam here generated, in addition to that required to supply motive power for the engines; efforts to economize steam within the factory are in great part useless unless economy is also practised in the combustion of the fuel. The subject of boilers, as such, is a special one of its own, and its discussion is quite outside the limits of a work such as the present; only a few points of special interest in the sugar factory are here mentioned.

Boilers.— In general boilers may be divided into a number of classes, such as external and internal fired boilers; the Lancashire, Cornish and marine boilers fall into the latter class, and these are quite unsuited for use with megass and other low grade fuels. All boilers used with such fuels are externally fired, and are (in comparison with coal and fuel oil fired boilers) provided with large external combustion chambers.

The boilers in use in sugar factories are almost entirely of the multi-tubular class, and these are divided into the *smoke tube* type, where the heated gases circulate within the tubes, and the *water tube* where they pass externally to the tubes.

The Smoke Tube Multitubular.—The smoke tube multitubular boiler consists of a cylindrical shell of length usually not less than twice the diameter; sizes 14 ft. × 7 ft., or 12 ft. × 6 ft are frequently met with. The boilers erected at the Puunene Mill of the Hawaiian Commercial and Sugar Company are 20 ft. × 7 ft., and this size is commonly used in the Hawaiian Islands; so great a length is objected to by some engineers on the ground that the part of the boiler remote from the furnace is very ineffective, but the results in fuel economy in the Hawaiian Islands are such as to leave no doubt in the writer's opinion that such objections are ill-founded.

In the end plates of the shell are drilled a number of holes into which are expanded tubes, generally about four inches in diameter; these tubes form the greater part of the heating surface. A boiler seven feet in diameter will have about 120 such tubes, and if fourteen feet long will have approximately 1,800 square feet of heating surface; increasing the length to 20 feet will give a heating surface of 2,600 square feet.

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The Water Tube Multitubular.—In the water tube multitu-
bular boiler the water is contained within the tubes, the products of combustion
circulating without the tubes.   The forms of water tube boilers most frequently
met with in sugar factories are the Babcock & Wilcox, the Stirling, the
Climax, the Hazleton and the Porcupine boilers.
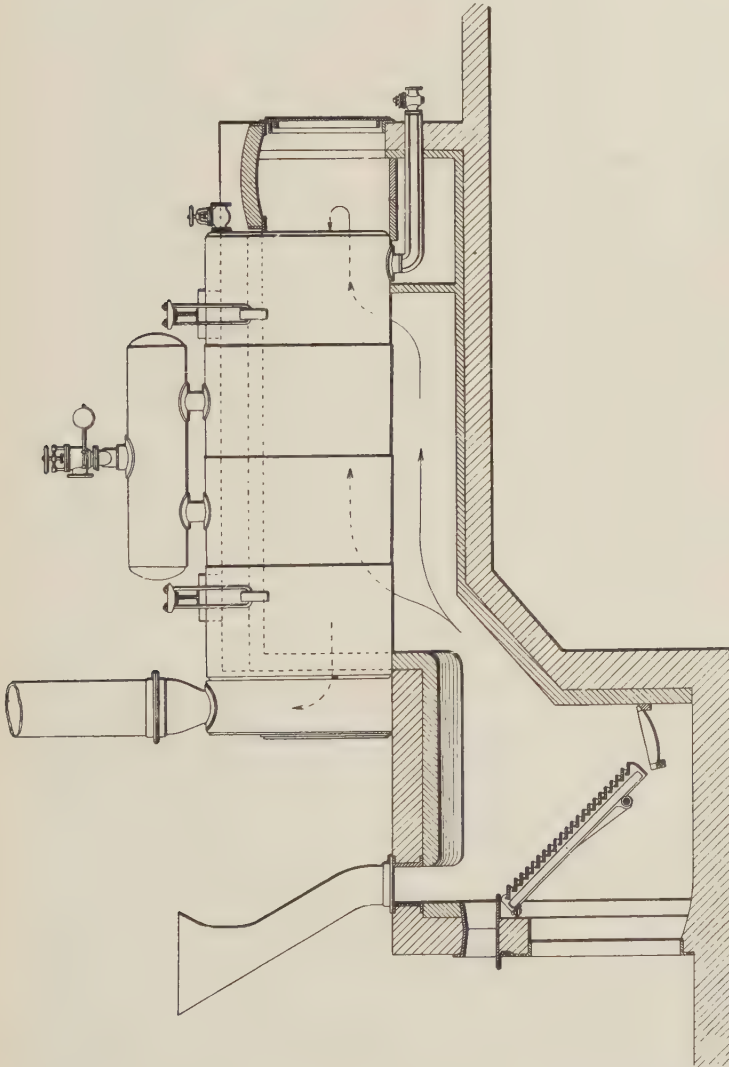
FIG. 218.

Water tube boilers have been largely erected in Demerara, in Cuba, and
in the West Indies; in the Hawaiian Islands, and in Java, however, the
practice has tended towards the smoke tube multitubular, although water
tubes are not uncommon in those districts.

Choice of a Boiler for a Sugar Factory.—Many years ago the late Hugo Jelinek wrote : "In a sugar factory, a type of boiler is to be chosen which has a large water capacity, so as to have always a provision of heat for unequal consumption of steam in the factory."

On broad lines the writer's experience has led him to endorse this view, and hence to prefer the smoke tube multitubular, in preference to the water tube, although many experienced engineers hold an opposite view. As far as economy in fuel goes, the question of the boiler is not a dominant one, and economy is chiefly a matter of furnace design and careful control of the combustion of the megass.

The water tube boilers have the advantage of being built in large units, of being adapted for high pressure, and of being capable of raising steam quickly, owing to their small water capacity; because of this small water capacity, however, any sudden load such as starting a pan with cold syrup may cause a sudden drop in pressure. Although it is for many reasons inconvenient to work at two pressures, a battery of water tube boilers at high pressure, supplying steam to the engines, and of smoke tube boilers at low pressure, supplying steam to the evaporators is a scheme that has much to be said in its favour.

Megass Furnaces.—In *Figs. 218* and *219* are shown views of the *Dutch oven* type of megass furnace; this type is largely used in Mauritius, in Louisiana, in Java, in Mexico, and in the Hawaiian Islands. In the diagrams the boiler is seen at *e*; the direction of the

Fig. 219.

products of combustion is first along the bottom and sides of the boiler, back through the tubes, and out to the smoke box, and thence to the main flue. In *Figs. 220* and *221* is shown what is known as the *Abel*[2] type of megass furnace, and is one largely used in Demerara. From the overhead shoot megass falls on the fire bars at *b*; the gases formed on combustion impinge on the arch at *e*.
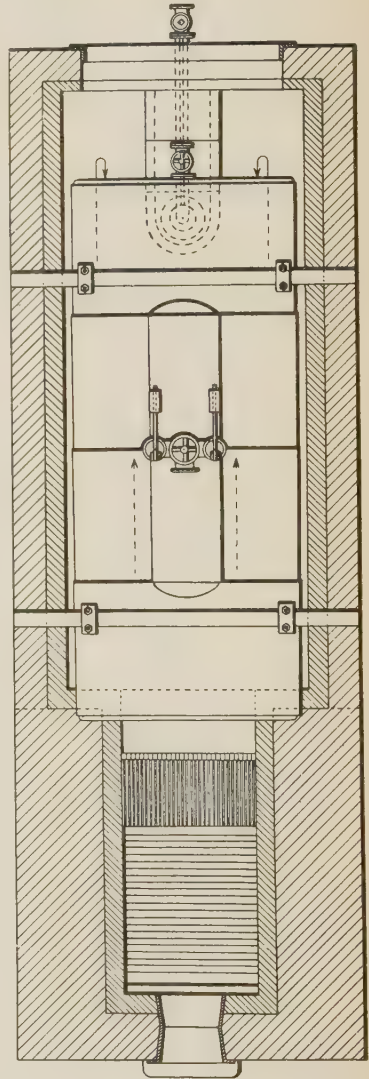
The air necessary for combustion enters at f, the space h forming a hot air reservoir; the ashes are removed at i; the boiler is shown at c. The passage of gases is first through the tubes, thence to the smoke box h, back along the sides and out underneath the boiler to the main flue g. In this design the flue gases pass three times along the boiler, as opposed to the two way pass in the Dutch oven setting.
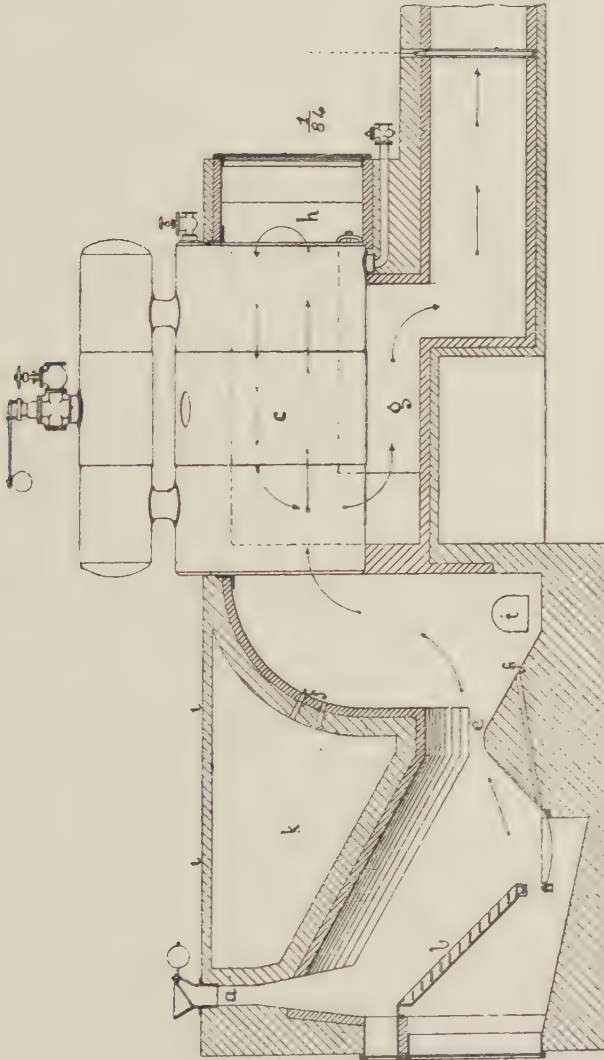
Fig. 220.

The Godillot furnace, *Fig. 222*, is a furnace of the Dutch oven type. The megass enters at b, being propelled forward mechanically by the screw c; the fire bars are arranged to form three sides of a pyramid, shown at d; air enters at e, and f is an aperture for viewing the combustion.

The essential difference between the Dutch oven and Abel type of furnace is the size of the combustion chamber; the first furnaces which the writer met with in his experience of the cane sugar industry were of the latter type, and he learnt that these large combustion chambers were thought necessary to obtain a complete combustion of the megass, and to avoid loss through the presence of carbon monoxide in the flue gases; with more extended experience the writer saw factories with the Dutch oven type of furnace working with extreme fuel economy, and with better results than others where the Abel type was in use. Radiation from the heated brickwork of the furnace is surely one of the principal sources of heat loss, and being proportional to the exposed area will tend to become very great in furnaces of exaggerated length, which the writer has seen as long as 28 feet from the face plate of the boiler to furnace door; in addition, the greater the mass of brickwork the greater is the opportunity for cold air to leak in through cracks in the masonry.

Stoking of Megass.—In recent factories the megass is fed to the furnaces by schemes mechanically as efficient as those used for automatically firing coal; a diagrammatic view of such a scheme is shown in *Fig. 223*; megass direct from the mill is delivered to a scraper carrier $a\,a$; this carrier is arranged to run in a direction at right angles to furnaces; over each furnace is placed a sheet iron hopper $b\,b$ and over the mouth of this is a shutter $c\,c$, the position of which is controlled from the platform $d\,d$ by means of a cord; the megass is carried forward by the scrapers $e\,e$, the quantity falling into the hopper being controlled by the position of the shutter; $f\,f$ are two toothed cylinders revolving inwards which serve to feed the megass

FIG. 221.

down the shoot; any surplus megass is directed on to the platform $d\,d$ by the shoot $g\,g$ and is, when required, fired by hand through the fire box door $h\,h$.
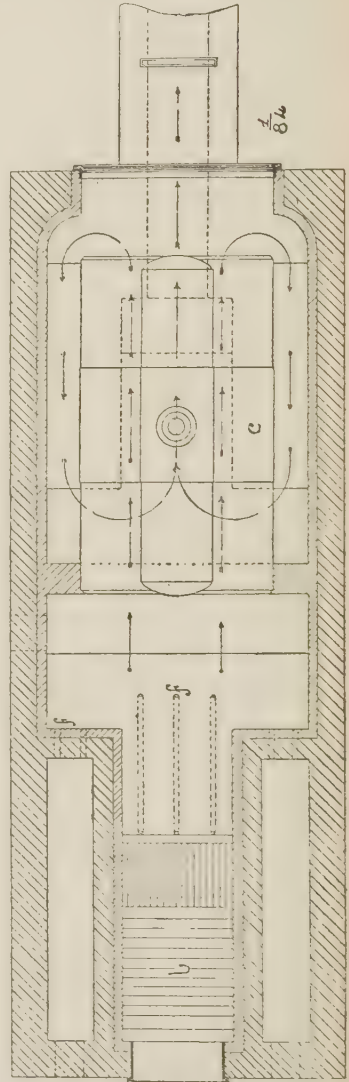
Relation between Cane ground and Requisite Heating Surface, etc.—The writer has had access to essential data on these points as they occur in a large number of well equipped modern factories and as a result has concluded that no average datum can be given, the variation in factories, all of which were working well, being so great. In the following table ' cane ' means the short tons of cane ground in 24 hours; 12 square feet heating surface in a smoke tube and 10 in a water tube are taken as the equivalent of one horse power; all surfaces are expressed in square feet :—

Ratio of	Maximum.	Minimum.
Horse power to Cane	2·4 : 1	·98 : 1
Heating surface to Cane	24 : 1	12 : 1
Grate surface to Cane	1 : 3·6	1 : 14·6
Grate surface to heating surface	1 : 54	1 : 343
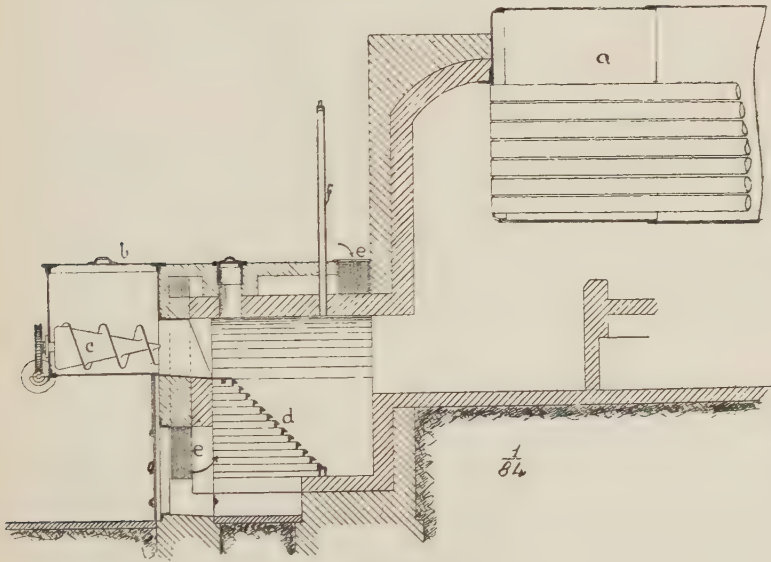
FIG. 222.

As shown in greater detail in another section, the thermal value of a pound of megass of fixed water content is sensibly constant, and hence it would appear reasonable that a fairly constant ratio of heating surface in boilers and hence of horse power would obtain; actually, the smallest variation in this ratio does obtain and the writer thinks that a ratio of heating surface to cane of 18 : 1 is ample and representative of good modern practice.

On the other hand, however, there is no reason for expecting any uniformity in the ratio between grate area and heating surface; this will of course depend on the intensity of draught, a smaller grate area being sufficient under forced or induced draught than under natural draught.

As will be explained in greater detail in a subsequent section, the weight of a cubic foot of megass from varieties (or even in different seasons from the same

variety) varies within large limits; hence a ratio which may be quite satis-
factory in one factory will be totally inadequate in another. The writer has
frequently observed that when the White Transparent cane was being milled
in Demerara the megass accumulated, but the supply could not be burned fast
enough on the existing grate area to maintain the supply of steam. This
difficulty, which may become a great deal more serious than a mere incon-
venience, could in the writer's opinion be overcome by the installation of an
additional furnace wherein megass would be fired only when occasion arose.
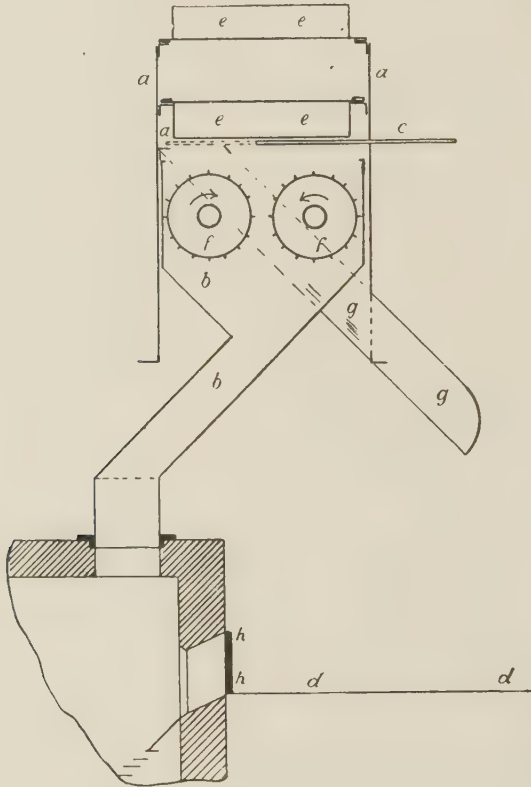
Fig. 223.

If this difficulty is really due to differences in the weight of a cubic foot of
megass, its cure is surely to be found in increased grate area rather than in
increased heating surface in the boilers.

Thermal Value of Megass.—The combustible bodies present in
megass are fibre, sugar, glucose and details of other organic bodies; the fibre
consists of cellulose proper, and xylan or wood gum. The heats of combustion
of these bodies as determined by Stohlmann and Langbein[3] are, cellulose, 7533
B.T.U., sugar, 7120 B.T.U., glucose, 6748 B.T.U. per lb. Taking these heats
of combustion as a basis, and assuming that the fibre has the same fuel value

as the cellulose, it is possible to calculate the thermal value of a megass ; thus, a megass of composition fibre, 42 per cent., sugar, 9·666 per cent., will afford, on complete combustion, ·42 × 7533 + ·0966 × 7120 = 3851 B.T.U. per lb. for the fibre and sugar alone, to which must be added that due to the glucose and other organic matter ; if this be taken as $\frac{1}{10}$ that due to the sugar, the gross thermal value of the megass will be 3920 B.T.U., and per unit of dry matter, supposing the megass contains 47 per cent. of water, 7396 B.T.U. The heat of combustion of megass of different origin has been experimentally determined by a number of workers. Geerligs[4], whose results are discussed more fully in another section, found the heat of combustion, per lb. of dry matter, to be sensibly constant ; his extreme values in B.T.U. are 8249 and 8514, with a mean of 8381 ; Burwell[5], in Louisiana, obtained a mean value of 8325, with extremes of 8289 and 8384. These values are considerably higher than would be obtained on calculation on the lines exemplified above ; actually, then, it will be sufficient, under average conditions, to accept a fixed value of 8350 B.T.U. per lb. of dry matter in a megass.

Products of Combustion of a Megass.—Each pound of carbon on combustion requires a theoretical minimum of 2·67 lbs. oxygen, a quantity supplied by 12·03 lbs. of air, the remainder, 9·36 lbs., being nearly all nitrogen ; at a temperature of 84° F. this quantity of air occupies 165 cubic feet. The combustible elements in megass contain hydrogen and oxygen in the same proportion that they exist in water, so that in calculating the air required for combustion only the carbon need be taken into account. Of the bodies present in megass, cellulose contains 44·4 per cent., xylan 45·4 per cent., sugar 42·1 per cent., and glucose 40·0 per cent. of carbon, so that from the analysis of a megass its carbon content can be found. In actual determinations Geerligs found megass to contain from 46·82 per cent. to 48·45 per cent. carbon, and from 6·30 per cent. to 6·67 per cent. hydrogen on the dry ash free material ; as an average then, per lb. of dry matter, a megass may be taken as containing 46·5 per cent. of carbon, and 6·5 per cent. of hydrogen, allowing that the dry matter contains 2 per cent. of ash.

Per lb. of dry matter, then, the products of combustion of a megass will be

Due to carbon .. .. .. $·465 × \frac{44}{12} = 1·705$ lbs. carbon dioxide.

Due to hydrogen.. .. .. $·065 × \frac{18}{2} = ·585$ lbs. water.

Due to nitrogen of air .. $·465 × 9·36 = 4·352$ lbs. nitrogen.

Fuel Value of Megass as influenced by Variety.—In "Sugar and the Sugar Cane" (page 280) it was stated that it was a matter of clinical observation that the megass from different varieties of canes exhibited very different values as fuel, and that this difference could *not* be accounted for by low fibre content of the cane or yet from the analysis of the megass. Similar

observations have apparently been made in Java, and the matter has been exhaustively enquired into by Geerligs[1], a summary of whose results is given below.

1. Actual determinations of the thermal value of the megass from different canes showed that the calorific value calculated to dry weight varied but little, and that the differences were entirely insufficient to account for the variation experienced in factory work. Of the samples examined by him the calories per kilogram of *dry* megass varied from 4583 to 4700.

2. The elementary composition of the ash free megass from different canes was determined, and those examined were found to give nearly identical results; expressed as per cents. of the dry ash free material, the megass contained from 46·82 per cent. to 48·45 per cent. carbon, from 6·30 per cent. to 6·67 per cent. hydrogen, from 44·94 per cent. to 46·43 per cent. oxygen, and from ·14 per cent. to ·18 per cent. nitrogen.

3. It was supposed that the fibre from the softer varieties of cane might contain more pentosans and xylan than that derived from the harder varieties, but the differences found were quite insignificant.

4. Differences in the cellulose content of the fibre were insufficient to account for the observed variation in fuel value, although as a general rule a cane rich in cellulose affords a satisfactory megass as fuel.

5. Differences in the silica content of the samples examined were trifling, and insufficient to account for the variations observed in practice; it was thought that perhaps a large quantity of easily fusible ash might coat the megass and prevent its combustion, or might choke the air inlets between the fire bars.

6. Great variation was observed in the volume occupied by the same weights of the megass from different varieties; the weight of 100 c c. of megass varied from 5·45 grms. to 7·95 grms., and the following observations were drawn :—

    a. The denser megasses were of superior fuel value.

    b. The denser megasses are generally rich in cellulose.

    c. Canes containing most fibre also give a megass of superior fuel value.

Looked at in the light of these determinations, the question of the fuel value of a megass is reduced to one of the mechanical structure of the fibre; a megass of low apparent specific gravity will thus occupy a large volume per unit of weight; the volume of megass which can be held on the grate of a furnace is limited, and with the megass of low density it may happen that the supply of fuel fed to the furnace is not sufficient to maintain steam for the factory's needs; when a different type of megass is being fired, owing to its greater apparent specific gravity a greater weight is contained on the grate without any change in volume, and steam is kept up without difficulty.

This matter is one of great importance in furnace design, as a ratio of grate area to heating surface which gives excellent results with the megass from one variety of cane may be quite insufficient when the megass from another variety is being stoked, although the total heat units available per ton of cane may be identical in both instances.

It must, however, not be overlooked that the quantity of fuel varies with the percentage of fibre in the cane, and that this cause will often explain a shortage of fuel; the results summarized immediately above tend to explain the state of an abundance of fuel and insufficiency of steam which most people connected with a sugar factory must have experienced.

Effect of Moisture on Thermal Value.—The difference in the thermal value of the same megass when the moisture varies from 48 per cent. to 52 per cent. is not very great, but Bolk[6] has shown that at about the higher limit the temperature of combustion is so lowered that decomposition products distil over incompletely burnt, and with this incomplete combustion very great heat losses occur.

Heat Available from Megass.—This calculation can best be shown by worked out examples.

Let the megass burnt contain 45 per cent. water and 55 per cent. dry matter; let the flue gases leave the boiler at a temperature of 550° F., the temperature of the atmosphere being 84° F.; let the air entering the furnace be twice the theoretical amount necessary for combustion; let the megass contain 46·5 per cent. carbon, and 6·5 per cent. hydrogen, calculated on dry weight, or 25·6 per cent. and 3·6 per cent. respectively, on actual weight.

To raise 1 lb. of water from 84° F. to 212° F. requires 128 B.T.U.; to convert this water into steam at 212° F. requires 966 B.T.U., and to heat this steam at constant pressure to 550° F. requires $(550 - 212) \cdot 48 = 162$ B.T U., the specific heat of steam at constant pressure being ·48.

Each pound of water vapour in the flue gases then carries away $128 + 966 + 162 = 1256$ B.T.U. The specific heats of carbon dioxide, oxygen and nitrogen are ·22, ·22, and ·24, respectively, so that each pound of carbon dioxide in the flue gases will carry away ·22 (550—84) B.T.U., and similarly for the oxygen and nitrogen.

On combustion each pound of carbon gives 3·67 lbs. of carbon dioxide, and each pound of hydrogen 9 lbs. of water.

Per pound of megass the products of combustion are then

Carbon dioxide	·256 × 3·67 =	·939 lbs.
Oxygen in excess air	·256 × 2·67 =	·683 ,,
Nitrogen	·256 × 2 × 9·36 =	4·792 ,,
Associated water		·45 ,,
Combined water..	·036 × 9 =	·324 ,,

The heat carried away in the flue gases is then

Carbon dioxide	$\cdot 939 \times \cdot 22\,(550-84) =$	96 B.T.U.
Oxygen in excess air	$\cdot 683 \times \cdot 22\,(550-84) =$	71 ,,
Nitrogen	$4\cdot 792 \times \cdot 24\,(550-84) =$	536 ,,
Associated water	$\cdot 45 \times 1256 =$	565 ,,
Combined water..	$\cdot 324 \times 1256 =$	407 ,,
Total		1675

The total heat generated by the megass on combustion is, following on a previous paragraph, $8350 \times \cdot 55 = 4582$ B.T.U. So that in this case the percentage loss in flue gases is 36·6 per cent., leaving 63·4 per cent., or 2905 B.T.U. available for making steam.

As an extreme instance of economical working let the flue gases (due to the use, say, of a fuel economizer) leave at 350° F., and let the excess of air be 50 per cent. Then the heat carried away in flue gases calculated on similar lines as in the case above is

Carbon dioxide	$\cdot 939 \times \cdot 22\,(350-84) =$	55 B.T.U.
Oxygen in excess air	$\cdot 341 \times \cdot 22\,(350-84) =$	40 ,,
Nitrogen	$3\cdot 694 \times \cdot 24\,(350-84) =$	236 ,,
Associated water..	$\cdot 45 \times 1160 =$	522 ,,
Combined water	$\cdot 324 \times 1160 =$	375 ,,
Total		1228

In this case, then, the total loss in flue gases is 26·9 per cent. of the heat value of the megass, and 3349 B.T.U. are left available for raising steam.

In addition, however, there are the losses in unburnt fuel, in hot ashes, and in radiation, the exact magnitude of which it is impossible to estimate. Probably these losses account for 5 per cent. to 10 per cent. of the total value of the megass; estimating them at the latter figure, in the first instance 2440 B.T.U., and in the latter case 2891 B.T.U. will form steam. The evaporation of one lb. of water from and at 212° F. requires 966 B.T.U., so that referred to this temperature and pressure, 2·55 lbs. of steam in the one case, and 2·99 lbs. in the second would be obtained.

As compared with coal firing the very great losses due to the associated and combined water met with in the combustion of megass and other low grade fuels should be noticed.

Consumption of Steam in Proportion to Available Fuel.

—In " Sugar and the Sugar Cane" the writer was at pains to calculate the heat required to treat the juice obtained from various types of canes, containing different amounts of sugar and fibre, both wet and dry crushed, and also crushed with the addition of maceration water, in order to see how far the megass would serve as fuel. The heat value of the megass was calculated

from its analysis, and since it is now known that heat values thus obtained are lower than those obtained by the use of the calorimeter, the calculations are to a great extent invalidated. Further, the writer has come to the conclusion that conditions in different districts are so widely variant that it is useless to select typical instances, and that the subject can only be treated on broad grounds, leaving it to those interested to adapt the general principles involved to their own special cases.

Effect of Fibre.—Properly speaking, the fibre alone should be considered as a fuel constituent of the cane, as the sugar is too valuable a constituent to burn; accordingly, the fuel produced by the cane will be in direct proportion to the amount of fibre; furthermore, where the canes are crushed without the addition of water, not only is the amount of fuel increased, but the quantity of juice to be treated is proportionately lowered. For example, let in one instance the canes contain 10 per cent. fibre, and in a second 14 per cent. fibre; let the megass contain 45 per cent. fibre; then in the first instance per 100 tons of cane 77·78 tons of juice and 22·22 tons of megass result; in the second instance, 68·89 tons of juice and 31·11 tons of megass. These differences are so large that one factory burning large quantities of extra fuel may be really working more economically, in so far as regards the production of steam, than one which has a surplus.

Effect of the Solid Content of the Juice on Steam required.—Let canes containing the same amount of fibre yield in the one case juice of 15° Brix, and in a second case juice of 20° Brix. Let the megass in both instances contain the same amount of fibre; then with a comparatively small error the available fuel will be the same. The evaporation of juice of 15° Brix to syrup at 55° Brix indicates the removal of $\dfrac{55-15}{55} = \cdot 7272$ parts of water per unit of juice; if the evaporation is done at quadruple effect, the equivalent evaporation at single effect is ·1818. The evaporation of juice at 15° Brix to massecuite at 95° Brix indicates the removal of $\dfrac{95-15}{95} = \cdot 8421$ parts of water per unit of juice; the evaporation to syrup required the removal of ·7272 water per unit of juice, hence the evaporation at single effect entails the removal of ·1149 parts water per unit of juice; the total evaporation, then, from juice to massecuite is equivalent to the removal at single effect of ·1818 + ·1149 = ·2967 parts water per unit of juice.

Similar calculations for a juice at 20° Brix initially give the evaporation to syrup at 55° Brix as equivalent to the removal of ·1591 part water per unit of juice, and the evaporation of the syrup to massecuite as equivalent to the removal of ·1532 part water per unit of juice, the total evaporation from juice to massecuite being equivalent to the evaporation at single effect of ·1591 + ·1532 = ·3123 part of water per unit of juice.

Actually, then, under factory conditions, a sweet juice demands a greater consumption of steam in evaporation than does an equal weight of one of less sugar content.

Relative Consumption of Steam in Different Stations in the Factory, and Potentiality of the Megass as Fuel.—

As a basis of calculation canes containing 12 per cent. fibre are assumed to afford a weight of diluted juice equal to that of the canes; the megass is assumed to contain 45 per cent. water and 55 per cent. solid matter, of which 50 per cent. is fibre; hence, per 100 (short) tons of cane there are obtained 24 tons of megass, which will afford on combustion 220,880,000 B.T.U., and if 65 per cent. of this be taken as available for steam, there results 143,572,000 B.T.U. per 100 short tons of megass. The Brix of the diluted juice is taken as 16°.

Heating Juice to Boiling Point.—Taking the specific heat of the solids as equal to ·301 that of sugar, the specific heat of the juice is $·84 + ·301 \times ·16 = ·888$. To heat 100 tons juice from 84° F. to 212° F. there are then required $100 \times 2000 \times (212 - 84) \times ·888 = 22,732,000$ B.T.U., or 15·8 per cent. of the the total available.

Cleaning Juice in Open Pans.—When making consumption sugars it is in some factories customary to clean the juice in eliminators; the writer has observed a concentration of from 1·5° to 2° Brix during this process. If the evaporation is taken as 10 per cent. of the weight of the juice, there are evaporated 20,000 lbs. water; for the evaporation of 1 lb. of water from and at 212° F. there are required 969·7 B.T.U.,* so that the consumption here is 19,390,000, or 13·4 per cent. of the total available.

Evaporation at Triple Effect.—It is supposed that juice is *not* cleaned in open pans, and that the syrup is turned out at 55° Brix. The evaporation is then $\frac{55 - 16}{55} = ·7091$ of the total amount of juice, or 141,820 lbs. of water from 100 tons of juice. Let each pound of water evaporated require 350 B.T.U.; then the consumption is $350 \times 141,820$ B.T.U. $= 49,637,000$ B.T.U., or 34·5 per cent. of the total available.

Evaporation at Quadruple Effect.—Each pound of water evaporated is assumed to require 290 B.T.U.; then the consumption is $290 \times 141,820 = 28·9$ per cent. of the total available.

Evaporation to Massecuite.—The total amount of water removed in repeated boilings of syrup and molasses is the same as if the syrup were in one process concentrated to that pitch which would give refuse molasses, provided the molasses resulting from the curing of various massecuites are not diluted previous to reboiling. Let the concentration of the massecuite be 96° Brix.

---

* This is the value very recently determined by Peabody, and replaces the older value, 966, found in all earlier tables.

PLATE XX.

FIG. 225.

The total evaporation from 16° Brix is then $\frac{96-16}{96} = \cdot8333$; in the evaporation to syrup $\cdot7091$ of the weight of the juice was removed, so that at simple effect in the pan $\cdot1242$ is removed, or 24,840 lbs. water per 100 tons of cane. At the prevailing vacuum in the pans each pound of water will require about 1070 B.T.U., so that the consumption of heat is 26,578,000 B.T.U., or 18·5 per cent. of the total available.

The above calculations are, the writer thinks, as far as the data available allow one to go. Experimental data are so absent that the consumption of heat in the motors, in losses in steam piping, in losses in the cooling of juices and syrups cannot be even approximated. It is of course in the heating and evaporation that the consumption of heat is greatest. Putting on one side cylinder condensation, but very little heat is used in the motors, and the great part of the heat of the steam entering the cylinders of the engine is available for evaporation.

In the calculations above with quadruple evaporation the total expenditure in heating and in evaporation of juices and syrups sums up to 63·2 per cent. of the total available, leaving a very large margin for use in other stations, on which definite values cannot be put.

It may then be stated that under ordinary conditions a sugar factory can be worked with a heavy maceration on the fuel provided by the megass, and that it is only under exceptional conditions (low fibre in cane, inefficient furnace and boiler settings, waste due to losses in steam piping, cleaning of juices in eliminators) that extra fuel is required.

Losses in Steam Pipes.—The following table gives the hourly loss in B.T.U. from naked wrought-iron pipes; this table is adapted from one given by Hausbrand and expressed in Centigrade metric units :—

Excess Temperature. F.°	Loss in B.T.U. per sq. ft. per hour.	Excess Temperature. F.°	Loss in B.T.U. per sq. ft. per hour.	Excess Temperature. F.°	Loss in B.T.U. per sq. ft. per hour.
40	80	140	370	240	749
60	131	160	436	260	832
80	185	180	509	280	925
100	239	200	580	300	1015
120	304	220	663	320	1120

The effect of lagging is shown in the following data, due to the same authority :—

A steam pipe at 275° F. and external air at 59° F. condensed per square foot per hour—

	lbs. steam.
Naked	·615
Lagged with silk waste 1 in. thick	·091
,, ,, cork shavings 2·2 in. thick ..	·095
,, ,, kisselguhr	·131 – ·183

i.e. the losses can be reduced about 80 per cent.

In a sugar factory the main steam pipes will be at a temperature of say 324° F., and the back pressure pipes at a temperature of say 224° F.; the average of these is 274° F., and assuming an equal area in main and back pressure piping it will be sufficient then to take the steam piping as having an excess temperature over the air of 200° F. From the table above then each square foot of unprotected piping will lose 580 B.T.U. per hour, and per 1000 square feet the loss is 580,000 B.T.U. If each pound of megass gives for use in the factory 2922 B.T.U., the loss per hour per 1000 square feet is very nearly 2000 lbs.; if 80 per cent. of this loss be economized by lagging, the loss per hour per 1000 square feet of pipe area is reduced to 400 lbs. amounting in a day of 24 hours to 9600 lbs. of megass. This rough and imperfect calculation is introduced to show the magnitude of heat losses in steam pipes and the differences which may be found between compact and straggling factories and between careful and careless equipment.

Heat Value of Megass as influenced by the 'Extraction.'—The samples of megass, the heat value of which was determined by Geerligs, contained but little sugar, and were representative of well exhausted megass; the thermal value of sugar is lower than that of the cellulose and xylan, so that with less well crushed megass the thermal value per pound of dry matter will tend to decrease, but only to a relatively small extent. Megass approximating to 46·5 per cent. carbon gave a thermal value approximating to 8350 B.T.U. per lb., or 17,978 B.T.U. per lb. of carbon. It might be sufficient to use this value in calculating the thermal value of a megass from its analysis which should include determinations of the cellulose, xylan, sugar and glucose.

Incidentally it may be remarked that these determinations of Geerligs and others show how incorrect is the use of ' Welter's ' rule which states that the heat of combustion of an organic compound is the heat of combustion of its elements, after deducting the hydrogen which will go to form water ; with the carbohydrates this would imply that their heat of combustion is the same as that of the carbon they contain. The heat of combustion of carbon is 14,400 B.T.U., so that a megass containing 46·5 per cent. carbon would only afford ·465 × 14,400 = 6696 B.T.U. as compared with the 8350 B.T.U. found on actual experiment.

Use of the Waste Gases to dry Megass.—In Mauritius many factories have erected apparatuses known as *sécheries* for the purpose of the utilization of a part of the waste heat of the flue gases. A *sécherie, Fig. 224,* consists of a large stone or brick chamber into which the flue gases are exhausted by means of fans; it is usually about 40 ft. long with an internal breadth of six or seven feet, and about 30 ft. high. The green megass is delivered into the *sécherie* by the carrier *a* falling on to the upper endless belt *b*; three such belts are usually provided; from the lowest the megass falls on to

the carrier c which conveys it to the furnaces. The carriers are formed entirely of metal and are driven at a speed of from six to eight feet per minute, the megass remaining in the *sécherie* from 15 to 20 minutes; the flue gases enter at d and leave through the smoke stacks at f; at g are shown doors for cleaning up the megass which falls to the ground, and at e a door gives access to the interior in case of accidents. Three engines are required, one to drive the fan, one to drive the carriers in the *sécherie*, and one for the cross-carrier from the *sécherie* to the furnaces. On an average as many as 15 to 20 labourers are required, chiefly for the purpose of sweeping up and carrying to the furnaces the megass which falls down. The megass in the *sécherie* is liable to ignite, and will invariably do so if the temperature of the waste gases exceeds 550°F. There is a very considerable and undeterminable mechanical loss due to the finer light and dry particles of megass being carried away; and finally the megass in the furnaces is so fine that it falls through the furnace bars, and is liable to be swept through the flues unburnt.
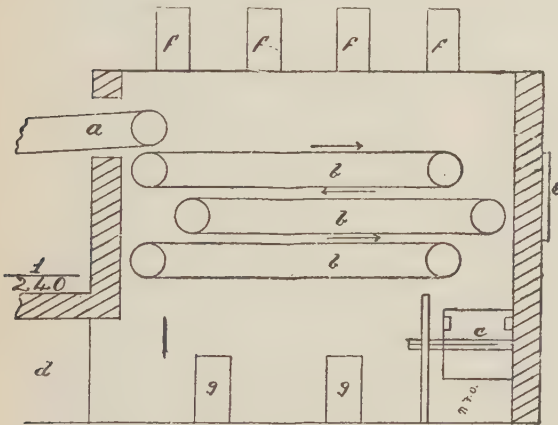
FIG. 224.

Another design to the same end is shown in the Huillard[7] Drier in *Fig. 225* (PLATE XX.). The economy of these devices can be shown by the following calculations.

In Mauritius the writer found that megass entering a *sécherie* with 50 per cent. of moisture would leave containing only 35 per cent.; this amount of water corresponds very closely with the evaporation of half the original moisture. In a calculation of heat lost in flue gases in a previous paragraph 565 B.T.U. per lb. of megass were found to be carried away in the associated water; a saving of half of this would be 282 B.T.U., reducing the heat carried away in flue gases to 1393 B.T.U., and expressed as a percentage on the total heat of megass the loss in flue gases will now be 30·4 per cent. as compared with 36·6 per cent. as previously calculated.

Value of Megass as compared with other Fuels.—The relative value of megass, wood and coal is often required, as fuel statistics are generally based on the coal value of the fuel burnt. There is no constant fuel value for either megass or coal, and any factor adopted depends on the local conditions; coal, depending on its quality and the skill used in firing, may give from 7 to 12 lbs. of steam per lb. consumed. On an average from 4 to 5

tons of megass are equal to a ton of average coal. Woods, weight for weight and of the same water content, have practically identical values; air-dried wood usually contains from 20 per cent. to 30 per cent. of water and from 3 to 3·5 tons are equal to a ton of average coal. Molasses are of very similar value to wood, the predominant factor being, of course, the water content. Cane straw contains as a rule about 10 per cent. moisture and from 2·5 to 3 tons are equal to a ton of coal. A table giving a comparison of fuel values follows :—

Fuel.	Gross B.T.U. per lb.
Welsh Steam	15,000—16,000
Pennsylvania Anthracite	15,000—16,000
Newcastle	14,000—14,500
Lancashire	14,000—14,500
Scotch	13,000—14,000
Australian	13,000—14,000
Indian	13,000—14,000
Patent Fuel	15,000—16,000
Air-dried wood 25 per cent. moisture	4,500—5,000
Green Megass 45 per cent. water	4,500
Cane Straw 10 per cent. water	7,500
Molasses 25 per cent. water	4,500
Petroleum	16,000—17,000
Carbon	14,400

Fuel Value of Molasses.—Molasses are occasionally used as fuel in sugar factories. Calculated from its analysis a molasses of composition— sugar, 35 per cent., glucose, 25 per cent., organic non-sugar, 13 per cent. water, 20 per cent., ash, 7 per cent., will afford on combustion about 4500 B.T.U. per lb.; actual determinations by Atwater[8] have given a value of 6956 B.T.U. per lb. of dry matter. The simplest, and a very efficient, way to burn molasses is to let it fall on to the megass on its way to the furnaces. In other cases the molasses are ‘atomised,’ and burnt in a special furnace, or, in conjunction with the megass, in the furnaces initially designed for their combustion.

Fuel Value of Cane Straw.[9]—Determinations of the fuel value of cane straw by Hoogewerf gave per lb. of dry matter 7841 B.T.U. per lb.; Koening and Bienfait found a value of 7407 B.T.U. per lb.

Control of the Fuel Consumption.—A factory working up 1000 tons of cane per day burns more or less 240 tons of megass; this megass is equal in value to about 60 tons of coal, and at the furnace mouth is then worth not less than £120 : if all this fuel were bought it is inconceivable that a most careful control would not be kept; even if no extra fuel is burnt economy in fuel may mean a higher dilution and better extraction, and in many cases any extra megass may be used in a distillery, as fuel for pumps, and in the future possibly as a source of paper. A fuel control may be obtained as indicated very briefly below.

Analysis of the Flue Gases.—With perfect combustion, *i e.,* with no excess of air, the fuel gases should contain 20 per cent. of carbon dioxide; in actual practice 15 per cent. is a very high figure and an average of 10 per cent. cannot be considered unreasonable. The best method for obtaining intermittent analyses of the flue gases is described below.
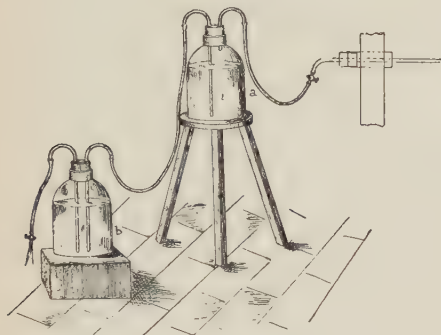
Collection of the Sample.—Specially designed bellows may be obtained from dealers, but the writer prefers to use the aspirator shown in *Fig. 226*; by adopting means for regulating the flow of water, a sample over several hours' duration can be obtained. The water in bottle *a* next to the flue is covered with a layer of oil. Before collecting the sample of gas the tube let into the flue should be well rinsed with the flue gases by means of alternately lowering and raising the bottle *b*.

For the analysis of the flue gases the following solutions are required :—

1. Caustic soda of density 60° Brix. For carbon dioxide.

2. Twenty-five grms. pyrogallol dissolved in 50 c.c. hot water and mixed with 100 c.c. caustic soda of density 50° Brix. For oxygen.

3. Cuprous chloride in hydrochloric acid. Dissolve 35 grms. cupric chloride in 200 c.c. hydrochloric acid of specific gravity 1·20; add a quantity of copper turnings, and preserve in a stoppered bottle for 48 hours with occasional shaking; then add 120 c.c. of water. For carbon monoxide.

The apparatus (Orsat-Lunge) shown in *Fig. 227* is the most con-

FIG. 227.

venient form for analysis. The bulb *b* is filled with caustic soda up to the mark on the neck, the bulbs *c* and *d* being filled in the same way with the pyrogallol and cuprous chloride solutions. The filling is performed by first
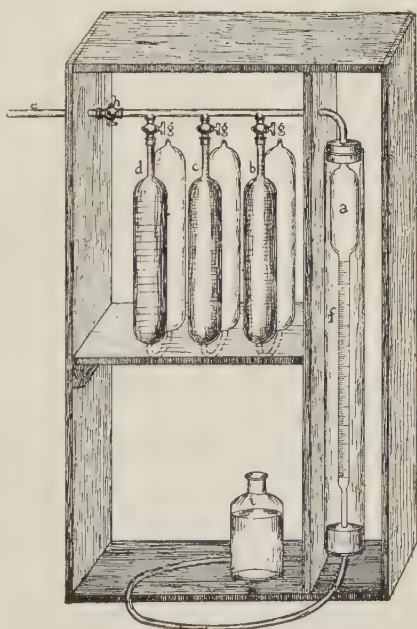
disconnecting the bulb and filling half way up by pouring in the solution; the bulb is then placed in position, the cock g opened, the bottle lowered, when the solution in the bulb rises and may be adjusted to the mark.

The burette a is to contain the measured volume of gas; it is first of all filled with water by raising the bottle i, the three-way cock h being open to the atmosphere and the cocks on the bulbs closed. The bottle containing the sample of gas is then connected with the tube e, the bottle i lowered, and the cock g opened to the sample bottle, the bottle b is then raised and the gas in a is forced into the burette; a little more than 100 c.c. is forced in, and then by raising the bottle i and opening the cock g to the atmosphere, exactly 100 c.c. of gas may be obtained in the burette a, the water level in a and i being the same. The cock g is then closed; the bottle i is raised, and the cock on b being opened, the gas is forced into the bulb b, where it is allowed to remain a short time; the cock on b is then opened, and by lowering the bottle i the unabsorbed gas is drawn back into a, and after adjusting the water levels in a and i the volume absorbed is read off the scale. The operation is repeated to make sure that absorption is complete; the process is repeated in the other bulbs; and the nitrogen is estimated by difference.

What is required, however, in a factory, is not an occasional record, obtained at the expense of much time and personal inconvenience, but a continuous record. Of the devices purchasable to this end the writer thinks the 'Simance-Abady' CO_2 Recorder the most perfect; this instrument gives with accuracy a continuous record of the per cent. CO_2 in the flue gases. Such a record affords the superintendent a complete control over the combustion.

Calculation of Excess of Air from Analysis of Flue Gases.—In air the nitrogen present occupies a volume of 3·74 times that of the oxygen. Hence if x be the percentage of oxygen, and y be the percentage of nitrogen found in flue gases on analysis, this equation results:

$$\frac{\text{Total quantity of air used}}{\text{Theoretical quantity}} = \frac{y}{y - 3 \cdot 74x}$$

If on analysis y is found to be 79·2, and x, 8·0, the excess of air is

$$\frac{79 \cdot 2}{79 \cdot 2 - 29 \cdot 9} = 1 \cdot 598,$$

or 59·8 per cent. more than the theoretical minimum of air is used.

Control from Temperature Observations.—From the composition of a megass and from determinations of its thermal value it is possible to calculate the temperature of the products of combustion; thus a pound of megass, which on combustion with the minimum amount of air gives ·939 lb. carbon dioxide, 2·394 lbs. nitrogen and ·771 lb. water vapour, and which is of thermal value 4592 B.T.U., will have a combustion temperature over and above that of the surrounding atmosphere of

$$\frac{4592}{\cdot 939 \times \cdot 22 + 2 \cdot 394 \times \cdot 24 + \cdot 771 \times \cdot 48} = 3988^\circ \text{ F.},$$

the specific heats of carbon dioxide, nitrogen, and water vapour being ·22, ·24, and ·48 respectively. If twice the quantity of air necessary for combustion was used, the combustion temperature will be

$$\frac{4592}{·939 \times ·22 + 4·788 \times ·24 + ·683 \times ·22 + ·771 \times ·48} = 2447°\,\text{F}.$$

since there are now 4·788 lbs. nitrogen and ·683 lb. oxygen in the flue gases.

The more air admitted to the furnaces the lower is the temperature, and hence observations of the temperature of the furnace give a means of overseeing the carefulness of the firing.

If the temperatures in the furnace, *i.e.*, the combustion temperature, and the temperatures of the waste gases be known, then the efficiency of the furnace can be at once obtained from the expression,

$$\text{Efficiency} = \frac{T - t}{T},$$

where T and t are the excess temperatures of combustion and of the waste gases over and above the temperature of the outside air; thus, if the combustion temperature be 1884° F., the waste gas temperature be 584° F., and that of the outside air be 84° F., then the efficiency is

$$\frac{1800 - 500}{1800} = ·7222,$$

perfect work being represented by unity. This calculation does not allow for heat losses due to radiation and to unburnt fuel, or to air leaks between the combustion chamber and the fuel, but will give strictly comparative results from day to day. The immediately preceding sections show how from the flue gas analysis and the megass analysis, first the excess air and then the combustion temperature can be calculated. What is required, however, in actual work is a continuous automatic record to which the mill superintendent can refer at his leisure, and immediately below attention is called to the very beautiful instruments which have been devised in the last decade for the accurate determination of high temperatures, and which are now to be obtained from dealers.

1. *Electric Resistance Pyrometers.*—The resistance of a conductor to the passage of an electric current is a function of the temperature prevailing in the conductor; this relation has been very carefully worked out for a number of conductors, and especially so in the case of platinum; hence if a current of fixed voltage or E.M.F. flow through a platinum wire, observations of the current produced give means of obtaining the resistance of the conductor by means of Ohm's law, current × resistance = voltage, whence from previously ascertained experimental observations the temperature of the conductor and (in the special instance considered) of the gases in the combustion chamber of the furnace are obtained. These instruments are constructed so that readings are obtained aurally by means of a telephone attachment, or visually by means of the deflection of a galvanometer needle.

2. *Thermo-Electric Pyrometers.*—If wires of two dissimilar metals be in contact at their ends, and if the temperature of the two ends be different, an electric current flows along the wire, and its voltage or E.M.F. is a function of the temperature difference between the heated and cold ends : this arrangement is called a thermo-electric couple, and by simply measuring the E.M.F. thus obtained, the temperature at the hot end follows. For high temperature work the thermo couple is made of platinum and rhodium, and will indicate correctly temperatures up to 2900° F.

3. *Radiation Pyrometers.*—In this instrument the rays of radiant heat emitted from a hot body are brought to a focus by a suitable combination of lenses and are directed upon the junction of a thermo-electric couple. From the E.M.F. or voltage the temperature is directly obtained.

4. *Optical Pyrometers.*—The optical pyrometer of Wanner is based on the colour produced by incandescent bodies : its theory is rather complicated. Externally the instrument closely resembles a polariscope, and it is used in a very similar way, being directed towards the body whose temperature is being determined : the critical appearance of the field of vision thus observed and the means of obtaining it are very similar to those used in polarimetry.

Of these instruments the first three can be provided with a continuous recording device. The electric pyrometers are perhaps not suitable for the very high temperatures of the combustion chamber ; this is chiefly due to the difficulty in protecting the platinum wire or the couple from the action of the furnace gases. The combination arranged by the Cambridge (England) Scientific Instrument Co. recommends a Fery radiation pyrometer for determining the temperature of combustion, and a thermo-electric couple for the flue gas and feed-water temperatures. A complete outfit costs less than £100, and in a factory of any size should quickly pay for itself.

Megass as a paper making Material.—Attention was first called to this possibility in Guadeloupe in 1872, and it has been frequently suggested during the last few years. Amongst the large amount of irresponsible matter that has been written the following definite statements have appeared :—

It has been stated that megass owing to its length of fibre yields a very good half stuff wrapping paper, there being a yield of 48 per cent. of half stuff from megass. The failure of experiments in Java is stated to be due to local conditions and not to the quality of the raw material. Thiele[11] has given a description of the results obtained with diffusion megass in a factory in Texas ; the crude material contained 82 per cent. water, 16·5 per cent. crude cellulose, ·75 per cent. carbohydrates and ·75 per cent. ash of which 82·77 per cent. was silica ; the megass was allowed to ferment in heaps with frequent watering whereby the pectins were destroyed ; a charge of 40,000 lbs. of fermented megass was boiled in a ' rotary ' for four hours under a steam

pressure of 90 lbs. per square inch with 450 lbs. dry soda and 250 lbs. quick-lime. After washing the material was ready to go to the paper machine.

The resulting paper is very strong and suitable for wrapping purposes; from 40,000,000 lbs. of chips 8,000,000 lbs.* paper were obtained, which sold at 2 cents. per lb. or £9·3 per ton. More recently paper making from megass, para grass (*Paspalum sp.*) bamboo, etc., has been initiated at the Tacarigua estate in Trinidad by Lamarre[12] where a material worth £5 per ton is stated to be produced.

A very recent examination of megass by Remington, Bowack, and Carrington[13] gives the following analysis of megass fibre : Water, 11·05 per cent. ; ash, 1·54 per cent. ; loss on *a*-hydrolysis, 30·01 per cent. ; loss on *b*-hydrolysis, 48·70 per cent. ; loss on mercerization, 32·73 per cent. ; gain on nitration, 10·21 per cent. ; cellulose 47·11 per cent. ; length of ultimate fibre, 3·5 mm. These authors speak very favourably of the possibilities of megass as a raw material for paper making, especially when mixed with other substances such as chemical wood pulp, lalang (*Andropogon caricosus*) and Para grass.

Finally, Raitt[14] comes to the following conclusion, based on very conservative figures :—

" Cane sugar factories are usually situated in localities where all manufactured goods have to be imported at a considerable cost for freight, and, probably, import duties also. Where such circumstances exist, together with a sufficient local demand for unbleached wrapping and packing papers, or even for the thin, unbleached paper so largely used by the natives of India and elsewhere for correspondence and accounts, it is quite possible to show that a paper mill may prove a very profitable auxiliary to a sugar factory, and that the megass may be worth considerably more for this purpose than its present fuel value.

A paper mill suitable for this class of paper, to produce 40 to 50 tons per week, would cost, roughly, £20,000. A conservative estimate of the cost of production, under average conditions, exclusive of the fuel value of the megass but including repairs, depreciation, and 5 per cent. interest on cost of plant, amounts to £10 10s. per ton. Under the conditions above referred to the product should be worth £15, leaving £4 10s. as the paper-making value of the 2¼ tons of megass required to produce it, or, say, £2 per ton. The cost of steam coal to replace it in the sugar factory furnaces would be at the outside £1 10s. per ton. In calorific effect a ton of good steam coal is usually assumed to be equal to four tons of megass, so that the full value of the latter cannot exceed 7s. 6d. per ton. Deducting this, there remains an estimated profit of £1 12s. 6d. per ton of megass converted into paper."

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* *i.e.,* 20 per cent. ; but the megass only contained 16·5 per cent. cellulose originally ; the figures are correctly quoted.

REFERENCES IN CHAPTER XX.

1. *Proc. Inst. Mech. Eng.*, December, 1902.

2. *Proc. Inst. Civ. Eng.*, *123*, 370.

3. *Jour. für Pract. Chem.* (2), *45*, 305.

4. *Arch.*, 1906, 445.

5. *La. P.*, 1896, 11.

6. *Arch.*, 1906, 319.

7. *I. S. J.*, 103.

8. *La. P.*, 1896, 11.

9. *Bull. Assoc. Abs.*, May, 1905.

10. *Papier Zeitung.*, *28*, 2891, abs. in *Jour. Soc. Chem. Ind.*

11. *Chem. Zeitung.*, *25*, 289, abs. in *Jour. Soc. Chem. Ind.*, *20*, 495.

12. *I. S. J.*, 114.

13. *World's Paper Trade Review*, October, 1909.

14. *Tropical Agriculturist*, January, 1910.

CHAPTER XXI.

THE POLARISCOPE AS APPLIED TO SUGAR ANALYSIS.

Ordinary light is the effect on the eye of vibrations of the ether, these vibrations taking place in all directions; by certain optical devices these vibrations may be confined to one plane, and such light is called *polarized light*. If such light pass through a layer of certain bodies, *e.g.*, quartz, cane sugar and many others, the plane in which the vibrations occur is rotated; these bodies are termed 'optically active,' and instruments devised for measuring the rotation of the plane of polarization are called *polariscopes* or *polarimeters*, and when specially applied to sugar analysis, *saccharimeters*.*

Laws governing the Rotation of the Plane of Polarization.—1. The angle through which the plane of polarization is rotated is directly proportional to the thickness of the layer of active material through which the light passes.

2. When the active body is in solution the angle through which the plane of polarization is rotated is directly proportional to the concentration of the solution, *i.e.*, to the amount of active material present.

3. The angle through which the plane of polarization is rotated is dependent on the temperature, the nature of the light, the nature of the solvent, and is affected by the presence of other bodies themselves inactive.

The law given in 2 above is only approximately true; in most cases it is true within the limits of the errors of technical assay. The first three disturbing factors mentioned in 3 are readily capable of control by always working under similar conditions; the last disturbing cause is not so amenable to control; fortunately in sugar analyses it is not a predominant source of error.

From the above it follows that, if the angle through which the plane of polarization is rotated be measured for any one concentration of a sugar solution, and if the length of the column of sugar solution through which the polarized light passes be known, then with a solution of sugar of unknown concentration the measurement of the angle through which the plane of polarization is rotated gives a means of calculating the concentration of the solution of unknown strength.

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* It is usually stated that the asymmetry of a carbon atom in the molecule of an organic body determines its optical activity; actually the asymmetry of a nitrogen, silicon or sulphur, or tin atom is equally sufficient; further Perkin, Pope and Wallach have at this present time (Dec., 1909) prepared an optically active body the activity of which is due to enantiomorphism of molecular configuration.

Specific Rotatory Power is the rotation at 20° C., expressed in angular degrees, of plane polarized light corresponding in wave length to that of the yellow D line of the solar spectrum, when the light passes through a column of a solution of the active material 10 cm. long, containing one grm. of active material in one c.c.

Kind of Light employed.—For scientific purposes it is necessary to refer all measurements to one source of light, and the light obtained from an incandescent sodium salt corresponding to the D line of the solar spectrum has been adopted. For technical sugar analysis polariscopes are adapted (in nearly all cases) to use ordinary white light. In what follows in explaining the use of polariscopes as apart from saccharimeters, it is assumed that the source of light is homogeneous and monochromatic.

For the theory of this source of light reference should be made to Landholt's classical treatise.
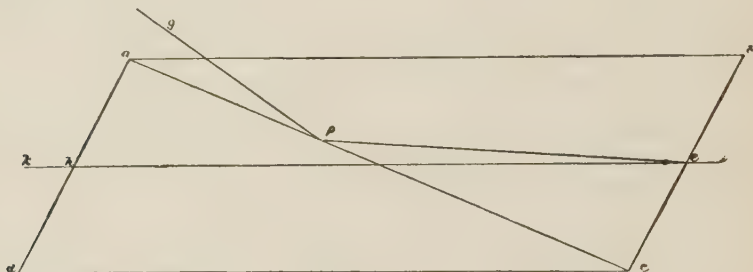
FIG. 228.

The Nicol Prism and Means of obtaining Polarized Light.—Polarized light is obtained for use in the polariscope by means of a nicol prism or some development of it. If ordinary light pass through crystals of certain bodies, of which Iceland spar is an example, it suffers double refraction, and is split up into two rays, one of which is known as the ordinary and the other as the extraordinary ray. A nicol prism is formed out of a prism of Iceland spar, the ends of which make angles of 71° and 109°; the ends of the crystal are ground until they form angles of 68° and 112°; the crystal is then split diagonally, and at right angles to the plane of the ends and to the principal axis, *i.e.*, along *a c*, *Fig. 228*; the surfaces are then polished and united with a film of Canada balsam.

Let *e e* represent a ray of light entering the prism; this ray is doubly refracted into two rays, one taking the direction *e p*, and the other the direction *e h*. *e p* is the ordinary, and *e h* the extraordinary ray; the ray *e p* on meeting the film of Canada balsam *a c* is reflected in the direction *p g*, and provided that the ends of the prism have been ground down to angles of 68° and 112°, will pass out of the prism before reaching the surface *a d*, and is totally lost if the sides of the prism are blackened. The extraordinary ray is less refracted, and emerges from the prism in the direction *k k*, and is now plane polarized light.

The original form of the nicol prism has been modified by several physicists ; the form used in the most modern instruments is that due to Glan, which is made as follows :—A symmetrical rhombohedral crystal, *Fig. 229*, is selected, and the two faces are ground down parallel to each other and perpendicular to the optical axis of the crystal; at right angles to these surfaces the prism *a b c d* is cut out, and split along the direction *b d* ; the faces of the prism and the surfaces at *b d* are then polished and the two parts cemented together along the surface *b d*.
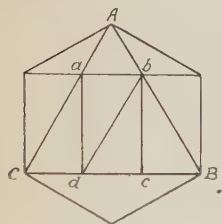
FIG. 229.

In this prism the field of vision is perpendicular to and symmetrical with the optical longitudinal axis of the prism, and reflection from the inclined surfaces as occurs in the ordinary form of nicol prism is eliminated.

Original Form of Polariscope.—Let there be two nicol prisms arranged with their two optical axes in one and the same straight line, and let a ray of light pass in the direction shown in *Fig. 230*, and as described in the preceding paragraph through the prism on the left, referred to as the *polarizer ;* and thence on to the similar prism on the right, referred to as the *analyser.* Dependent on the relative positions of the prisms all, a part, or none of the light will reach the eye of an observer looking from right to left towards the source of light; if the prisms are set so that their principal axes are parallel a maximum of light passes ; if set so that their principal axes are not at right angles to each other, none of the light passes.   This position is referred to as *crossed nicols ;* between these two positions a portion of the light passes.
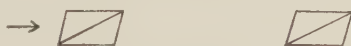
FIG. 230.

Now let the two nicols be crossed, then no light reaches the eye of the observer ; if, now, an optically active material be interposed between the two nicols so that the plane in which the polarized light vibrates is rotated, a portion of the light passes, and to obtain the effect of total darkness the analyser must be rotated about its longitudinal axis through an angle equal in magnitude, but opposite in sign to that through which the plane of polarization has been rotated by the optically active material; now if to the analysing prism a pointer be attached, which indicates zero on a scale at the position of crossed nicols, then the angle through which the prism has to be rotated to again produce the position of total darkness measures the rotation due to the optically active material.

The first polariscopes constructed by Biot[2] actually obtained their reference point in this way ; but the position of total darkness is not one which can be accurately determined, and other devices are described below.

Transition Tint Device.—White light is the effect on the eye of red, orange, yellow, green, blue, indigo, and violet rays; these rays are, when polarized, differently rotated in their passage through active bodies; if, then, we have two nicol prisms arranged as in the preceding paragraph, with their longitudinal axes parallel, and rotate, as by the interposition between the two nicols of an optically active material, any one of these components of white light through 90°, that component will be eliminated, and will not reach the eye of the observer; if the yellow rays are thus eliminated the rest combine to form a peculiar pale rose or lilac tint termed the transition tint; the yellow rays are rotated 90° by a plate of active quartz 3·75 mm. thick.

This device, originated by Robiquet, and constructed by Soleil, consists, then, in the interposition between the analyser and polarizer of a plate of quartz 3·75 mm. thick, one half of which is of dextro- and the other of levo-rotatory quartz; then if the nicols are parallel the field of vision (using ordinary white light) is a uniform pale rose tint, and the pointer attached to the analyser should indicate zero. Now, if the analyser be rotated but a little, or if the plane of polarization be rotated by the interposition of an active material, the proportion of red, orange, &c., rays in the two halves of the field that reach the eye of the observer is different, on the one side red on the other side blue rays predominating. This contrast between red and blue is very pronounced, and measurement of a rotation is obtained as described before by rotation of the analyser through an angle equal in magnitude, but opposite in sign to that due to the material whose activity is being measured.

This instrument then obtains its reference point by the elimination of the yellow ray of white light, and measures the rotation of this ray. Specific rotations obtained with this instrument are referred to as $[a_j]$; (French *jaune* = *yellow*).

The Half Shadow Devices.—In all these instruments the reference point is a uniformly tinted field; on introducing a very small rotation one half of the field becomes darker in tint than the other, the change being very sharp. With rotation far removed from that giving the reference point a field of vision approximately uniformly tinted is also observed, and may be distinguished from that connected with the reference point by there being no sharp change on introducing a small rotation of the plane of polarization.

The Jellet-Cornu Half Shadow Device.—This half shadow arrangement was originally devised by Jellet[3] in 1860, and since then has been elaborated by many physicists. As made by Jellet, between the polarizing and analysing nicols, and close to the former, was interposed a right prism of Iceland spar; this prism was sawn through lengthwise, the opposite faces ground down to equal angles, and the two halves cemented together in reversed positions, so that they made an angle a with each other; this angle is called the half shadow angle. The Jellet prism was modified in 1870 by Cornu[4]

thus. An ordinary nicol prism (*Fig. 231*) is bisected in the direction of a plane passing through the shorter of the two diagonals; the sectional faces are cut down 2½°, and the two halves reunited. In this way is obtained a double nicol prism with two principal sections at an angle of 5° to each other. Now in *Fig. 232* let *a f* and *e d* represent the positions of the planes of polarization of an analyser and polarizer of ordinary construction, when in the position of crossed nicols; that is to say, *a f* and *e d* are at right angles to each other. Now if a prism as devised by Cornu be substituted for the polarizing nicol, the plane of polarization will now be represented by the line *c o b*; let the analysing nicol be rotated so that its plane of polarization is *a f*, perpendicular to *o c*; then that half of the field of vision will be in total darkness, but the other half will be illuminated. Similarly, the right hand half of the field of view can be made totally dark, and when the plane of polarization of the analysing nicol is in the position *a f*, the whole field is equally illuminated, and this position forms the critical position. This position is one of great delicacy, and a small change from the position *a f* results in unequal illumination. If the analyser be
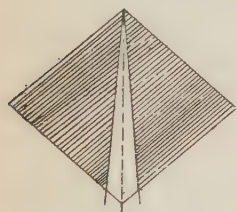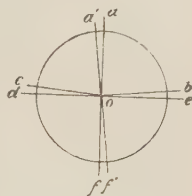
FIG. 231.

FIG. 232.

rotated so that it comes to the position *d e*, both halves of the field are strongly illuminated, and receive nearly a maximum of light, but on slightly rotating the analyser there is no sharp change as occurs when the plane of polarization of the analyser is in the position *a f*.

The Lippich Half Shadow Device.—This device, which is now used in the best instruments of German make, obtains its half shadows by the interposition of a small Nicol prism between the polarizer and the analyser, as shown in *Fig. 233*. The half nicol is so fixed that its edge, *C*, lies in the axial plane of the apparatus, and divides the field of vision into two halves. Let the principal sections of the two prisms make an angle, *a*, with each other. Light passing through the large nicol, *a*, and through the open part of the field, vibrates vertically to the principal section of that prism. Of the rays that pass through that half of the field covered by the half nicol, only those pass that vibrate vertically to the principal section. A field of vision is thus obtained made up into two halves in which the planes of polarization are inclined at a small angle to each
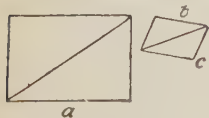
FIG. 233.

other, and the effect is precisely as described when dealing with the other forms of half shadow instruments. In this instrument the analysing nicol is not set parallel to the polarizing nicol, but makes with the polarization direction of the half nicol a larger angle than it does with that of the large nicol, so as to correct for the absorption of light which occurs in the passage through the small nicol.

The Laurent Half Shadow Device.[6]—The Laurent half shadow polariscope obtains its end point in a manner quite different to the instrument described above. Between the polarizing and analysing nicol of ordinary construction, and close to the former, is interposed a thin plate of active quartz, which is cut parallel to the optical axis of the crystal. A beam of light entering such a plate perpendicular to its surface, is doubly refracted into two beams, with vibration planes parallel, and perpendicular to the optical axis. In such a system that ray which vibrates perpendicular to the optical axis has its speed of vibration increased, and the thickness of the plate of quartz is so taken that that ray vibrating perpendicular to the optical axis has gained half a wave length on the wave vibrating parallel to the optical axis at the moment they emerge from the quartz plate. In *Fig. 234* let the circle represent the diaphragm opening, covered as to one half by the quartz plate, and let the optical axis of the plate be represented by the line *o b*; let *o a* represent the amplitude of vibration and the plane of polarization of the light coming from the polarizing nicol. On meeting the quartz plate this ray is resolved into two rays, *o b* and *o e*, parallel and perpendicular to the optical axis of the quartz plate; on emerging from the quartz plate the ray *o e* has gained half a wave length on the ray *o b*, and is now represented by the line *o d*. These two rays can be compounded into the ray *o c*, precisely as if the field of vision was illuminated by the rays *o a* and *o c*, symmetrically arranged with respect to the optical axis of the quartz plate. The effect of this is to obtain a field of vision exactly similar to that described in dealing with the Jellet-Cornu apparatus, and the remarks made there are applicable. It must

FIG. 234.

be noted that the half shadow angle with this instrument can be varied, the larger the angle the greater the intensity of the light, but the less the delicacy of the apparatus. With this apparatus very dark-coloured materials can be observed, but with a loss in the fineness of the reading.
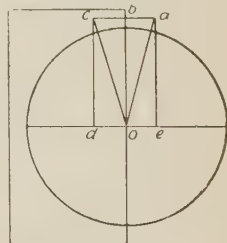
Horsin-Deon Polariscope.[7]—This instrument is of different construction to any of those previously described. The light passes through a Jellet prism, and then through a plate of dextro-rotatory quartz rather more than 4 mm. thick; the effect of this is to produce a blue field on the left and a pale yellow field on the right. The compensator is a wedge of levo-rotatory quartz, behind which is placed a disc of levo-rotatory quartz, the effect of which is to produce a final tint rather darker than the sensitive tint of the colour polariscope. This field of view of this instrument in positions remote from the zero position is that one half is colourless, and the other coloured in all colours of the spectrum. Near the zero position the colourless half becomes tinted before the other half loses its colour; at the zero position, the field of view is a uniform field, similar to that of the half shadow instruments.

Wild Polariscope.[9]—This pattern, which is seldom met with, obtains its end point by means of the interposition of a Savart polariscope between the polarizer and analyser, the former being rotated in making a reading. When adjustment is nearly obtained a number of horizontal dark bands occupy the field of vision; on further rotation of the polarizer those occupying the centre of the field disappear, leaving a clear, bright, vertical band, defined by a circular banded part on either side; in the field of vision are arranged cross hairs, the end point being taken when the three parts of the field are symmetrically arranged about these.

Trannin Polariscope.—In this instrument the analyser and polarizer are fixed, and adjustment is made by varying the length of the polariscope and concentration of the solution.

Broch Polariscope.—This instrument combines the spectroscope with the polariscope and obtains its end point by the coincidence of a dark band in the field of vision with the Fraunhofer D line. These last two instruments find no use in sugar analysis.

The Saccharimeter as distinct from the Polariscope.—In the above descriptions of devices used in polariscopes it was stated that the angular rotation was measured by rotating the analyser in an opposite direction to that due to the active material, the rotation being measured directly in angular degrees, and that monochromatic spectrally purified light was used. In polariscopes made specially for sugar analysis ordinary white light is used, the rotation is measured on a linear scale graduated up to 100°, the 100 point corresponding to the rotation produced by *normal weight* of pure sugar dissolved in 100 cc., and observed in a tube 20 cm. long; the rotation produced by the sugar solution is neutralized by the interposition of a plate of active quartz, the thickness of which can be varied, and which is proportional to the scale reading, the device being known as a compensator.

Normal Weight.—By this term is meant that weight of pure cane sugar which, dissolved in 100 cc. of water, and observed in a tube of length 20 cm., gives a reading of 100 on the scale of the polariscope.

There are several normal weights in use. Ventzke, the optician, whose name is connected with the transition tint polariscope, adopted as a standard sugar solution, one of density 1·1, at a temperature of 17·5°C.; such a solution contains 26·048 grms. of sugar in 100 Mohr's c.c., and this weight of sugar became a very generally accepted normal weight. Mohr's c.c., *i.e.*, the volume occupied by a grm. of water at 17·5°C., is deservedly falling into desuetude, and since 26·015 grms. per 100 true c.c. are equivalent to 26·048 grms. per 100 Mohr's c.c., a normal weight of 26 grms. per 100 true c.c. has been strongly recommended for adoption.

The second normal weight, used in instruments of the Laurent pattern, and in the old Duboscq instruments, is based on the angle through which the plane of polarization of the D ray of sodium light is rotated by a plate of quartz 1 mm. thick, cut at right angles to its optical axis; this angle, when the sodium light obtained by vaporizing sodium chloride in a bunsen burner is filtered through potassium bichromate, is 21·667°, and this is the rotation produced by a solution of 16·29 grms. of sugar in 100 true c.c., whence this weight of sugar was adopted as a standard normal weight. This normal weight has been much confused; the early Duboscq instrument used 16·35 grms. as a normal weight; other instruments were standardized for a normal weight of 16·19 grms.
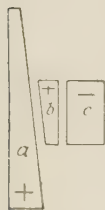
FIG. 235.

The confusion has in part arisen by determinations of the optical activity of quartz under conditions other than those originally stipulated; actually, the rotation of quartz is immaterial, so long as it is known for what normal weight and for which cubic centimetre the instrument has been constructed.

The Compensator.— The compensating arrangement consists of a device whereby a variable thickness of active quartz may be interposed and a rotation equal in magnitude and opposite in sign to that due to the active material introduced, so that the reference point again appears; the compensator used in most sugar instruments is shown on an enlarged scale in *Fig. 235*; it consists of a plate of levo-rotatory quartz c, and of two wedges of dextro-rotatory quartz, a and b; by means of a rack and pinion gear one of the wedges is capable of being slid past the other, so that the combined thickness of the system is capable of being varied; on the moving wedge is fixed a scale graduated in single degrees from − 30 to + 105; on the fixed plate of quartz is mounted a vernier. When the scale is at zero, the combined thickness of the dextro-rotatory wedges a and b is equal to that of the levo-rotatory plate c, so that the effect of the system is zero. By sliding the scale towards the 100 point a diminished thickness of dextro-rotatory quartz is introduced, so that the effect of the system is levo-rotatory, and at the 100 point exactly neutralizes the rotation produced by the normal weight of sugar dissolved in 100 c.c., and observed in a 20 cm. tube.

Reading the Scale.—The scale of these instruments is shown in *Fig. 236*; it consists of two parts, the lower one fixed, and the other sliding, and moved simultaneously with the adjustment of the compensator. The line at which the reading is taken is that marked O in the upper scale.
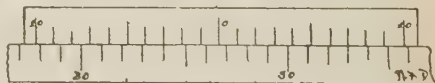
FIG. 236.

At the zero position this line is continuous with that line marked O in the lower scale. To take a reading the position of the zero line on the upper scale is noted with respect to the lower scale. In *Fig. 236* this is between 26 and 27. It is next observed what lines on the two scales are continuous; in this case the seventh, counting from zero. The full reading is then 26·7.

External Form of Polariscopes. — The instruments most frequently met with in sugar houses are made by Schmidt & Haensch, Fric, and Peters. *Fig. 237* shows a late pattern adopted by the first-named firm : at the end next the lamp is a tube with a diaphragm in which may be inserted at will
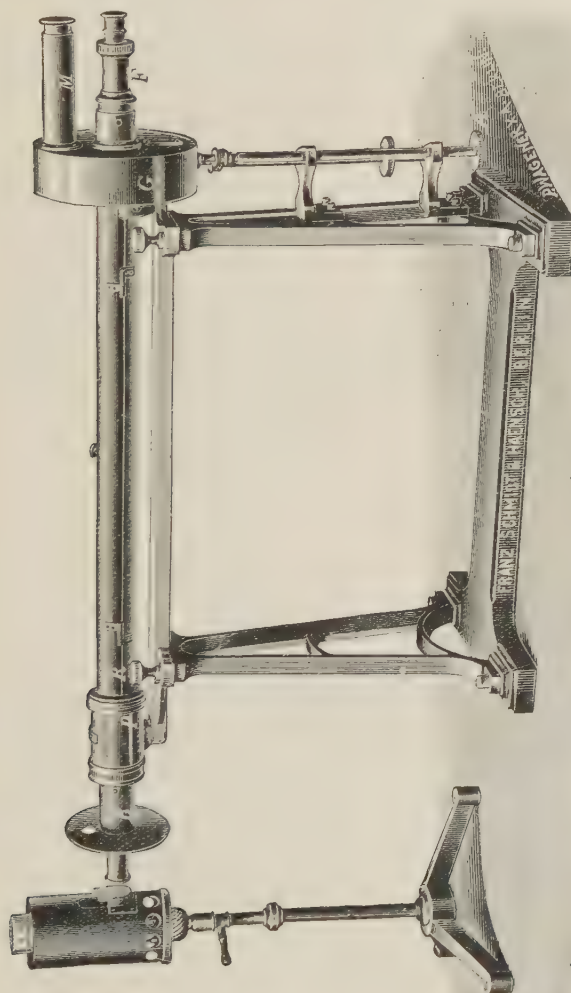
Fig. 237.

a ground glass disc ; by the use of this, equal illumination can be obtained when using an electric light or incandescent mantle. At *B* is a chamber serving to hold a cell which may be filled with a dilute solution of potassium bichromate ; at *P* is contained the polarizing apparatus ; at *R* is the trough of the instrument designed for the reception of the tube containing the sugar solution ;

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within the dust-proof casing G is contained the system of quartz wedges forming the compensator; F is the telescope which focusses the field of vision; in the enlarged part of F, *i.e.*, between the letters F and G is the analyser; M is a telescope whereby the scale is read, it being illuminated from the lamp light passing through the aperture in the light shield at B. The pattern shown is a double wedge compensating instrument, the milled head controlling the working wedge being seen at A; the extension of this to the table saves much fatigue where many consecutive analyses are made.

The pattern adopted by Peters is shown in *Fig. 238*; in arrangement of parts it is nearly identical with the pattern adopted by Schmidt & Haensch. The instruments made by Messrs. J. & J. Fric (*Fig. 239*) are also similar to the above in arrangement of the optical parts; the scale illumination is,
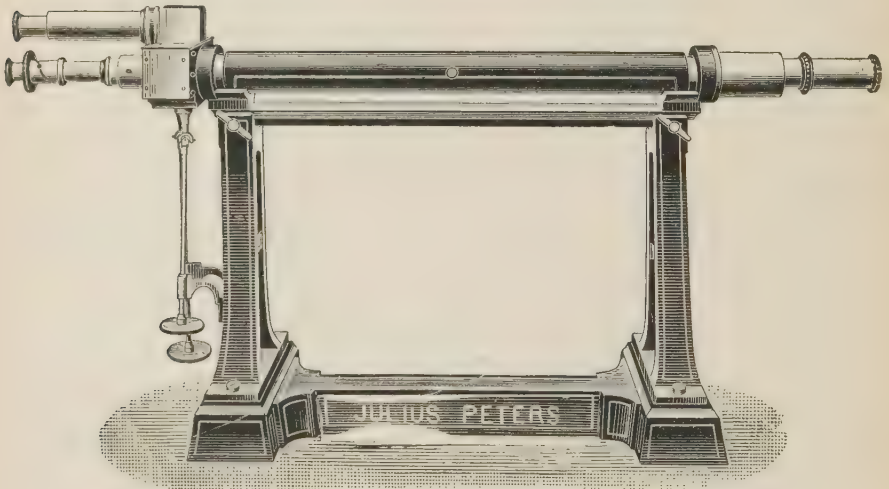
Fig. 238.

however, made differently. Within the body of the instrument, next to the source of light, is a reflector, inclined at 45°; a diaphragm therein allows light to pass on to the polarizer; the other part of the light is reflected to a vertical silvered mirror which throws a pencil of light on the scale.

Adjustable Landholt-Lippich Polariscope.[8] — As usually made, these instruments, when designed specially for saccharimeters, have a fixed half shadow angle; the smaller the half shadow angle the less is the intensity of light, and the greater is the delicacy of the instrument; very light-coloured solutions can be read with a low intensity of light, but for dark-coloured solutions it is often advisable to increase the half shadow angle, and

to sacrifice the delicacy of the reading in order to obtain the passage of more light, the accuracy of the observation being thereby increased. An instrument using the Landholt-Lippich half shadow device, and in which the half shadow angle can be varied at will, has been devised by Bates, and constructed by the firm of J. and J. Fric. The analysing nicol and the polarizing nicol are mounted in bearings, and are joined by gears with a connecting rod; the gears are controlled by the rotation of a milled head, and are such that the rotation of the analyser is always twice that of the polarizer. A scale attached to the milled head gives the half shadow angle.
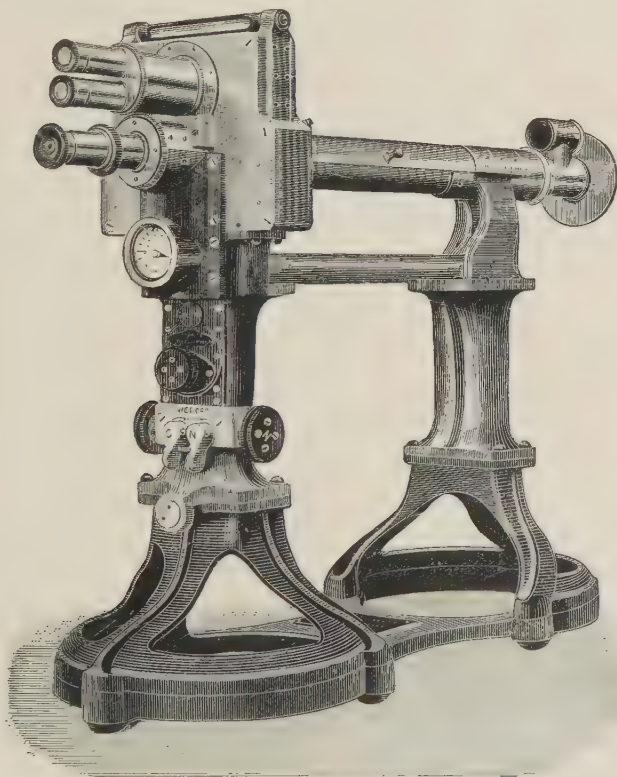
Fig. 239.

The zero of the instrument is affected by a change in the half shadow angle; with an instrument adjusted for a half shadow angle of 10°, the latter may be varied from 4° to 12·4° with the introduction of an error of less than ·1 Ventzke. Bates has worked out the corrections to be made for different half shadow angles when the instrument is in adjustment for the latter equal to zero, and this can be made practically instantaneously, the half shadow angle being indicated as already mentioned.

It is claimed that the polarization of the better grades of sugar can be read with this instrument to ·01 Ventzke.

Optical Parts of Polariscopes.—Below are mentioned the arrangements of the optical parts of such polariscopes as are to be found in general use.

Soleil-Duboscq.—The optical parts are shown in *Fig. 240*: *a*, colour compensator; *b*, lens to make rays of light parallel; *c*, polarizer; *d*, biquartz plate; *e*, compensator; *f*, analyser; *h g*, focussing telescope. The colour compensator consists of a nicol prism and plate of quartz. When dark-coloured

Fig. 240.

Fig. 241.

Fig. 242.

Fig. .243.

Fig. 244.
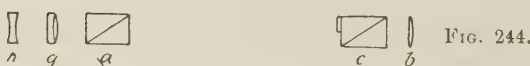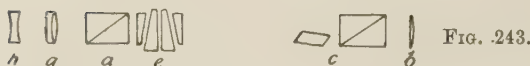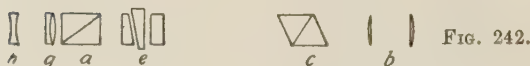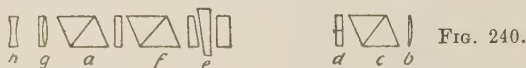
solutions are being examined the transition tint does not appear, but an approximation thereto may be obtained by rotating the colour compensator. The scale of this instrument is not provided with a vernier, divisions of less than one degree being estimated by the eye; the normal weight is 16·35 grms.

Soleil-Ventzke-Scheibler.—The optical parts are shown in *Fig. 241*; reference being as in *Fig. 240*; the colour compensator is placed next to the lamp, and in mechanical details this instrument is superior to the Soleil-Duboscq.

The Jellet-Cornu Half Shadow.—The optical parts are shown in *Fig. 242*, the reference being as in *Fig. 240*.

The Landholt-Lippich Half Shadow.—The optical parts are shown in *Fig. 243*.

The Landholt-Lippich Triple Shade.—The optical parts are as for the half shadow, except for the polarizer, which is shown in *Fig. 245* two small nicols of exactly similar construction and adjustment are used so that the field is divided into three parts; in all positions except when equality is obtained there appears a black band in the centre of the field, bounded by a light portion on either side, or vice versa; this device is of great sensitiveness, but, owing to the great delicacy of the adjustment of the reference point device, is not to be recommended for use where access to an optical instrument expert is difficult.

The Laurent Half Shadow.—The optical parts of the early Laurent instruments are shown in *Fig. 244*; these instruments used the sodium light and compensated by rotation of the analyser; the normal weight was 16·19 grms. in 100 true cc.

FIG. 245.

The modern form of the Laurent instruments is shown in *Figs. 246* and *247*; these instruments are now made so that by an adjustment either the sodium light or white light may be used; in the former case, compensation is effected by rotation of the analyser, and in the latter by quartz wedges.

Laurent instruments are constructed in which the lamina of the quartz securing the half shadow device is inserted as a circular disc, concentric with the field of vision.

Polariscope Lamp. — When ordinary white light is used it is essential that it be as bright as possible; an ordinary duplex paraffin lamp, carefully trimmed, gives good results; better results still are obtained by an incandescent mantle with gas or alcohol as the source of light, and the acetylene lamp gives perhaps the best illumination. The incandescent electric light is also convenient, but requires the interposition of a ground glass disc. Some years ago lamps supplied from the makers of polariscopes were fitted with a metal chimney, in which was a bull's-eye lens. This is not only unnecessary, but even objectionable; it is, however, convenient to enclose the source of light in an asbestos chimney provided with a narrow opening, towards which the polariscope is directed; this arrangement is to shield the eye of the observer from extraneous light. The distance of the lamp from the instrument is of importance, and in modern instruments it is from 15 cm. to

20 cm. ; actually, the lamp should be so placed that an image of the source of light is formed by the illumination lens on the analyser diaphragm. This position can be easily determined ; a pencil point is held immediately in front of the source of light, and a piece of paper in front of the diaphragm ; at the correct position a sharp image of the pencil point is formed on the paper.
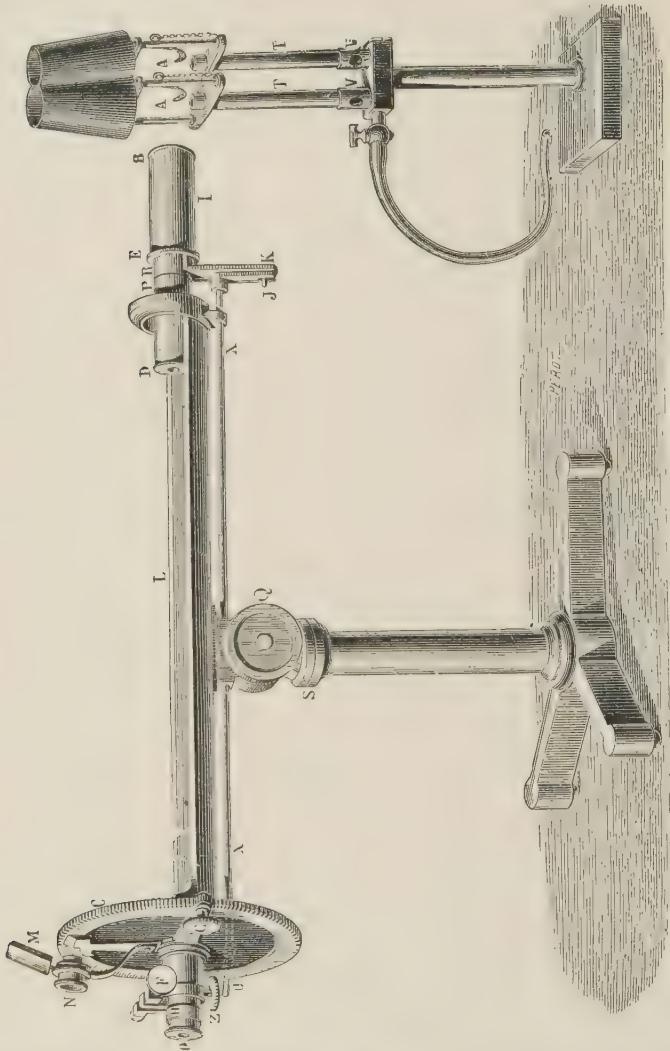
FIG. 246.

In most text books it is recommended that the polariscope be used in a dark room, and sometimes that the source of light be in a separate room, a narrow slit being cut in a wall of the room. In general this scheme is inconvenient, and confinement in such a place is, in the tropics, objectionable The writer finds that extraneous light may readily be excluded from the eye by the following device :—A piece of copper is beaten out into the form of the

cups used to apply eye washes, and a sprung shank is soldered on to this cup, forming a piece as in *Fig. 248*; this is fixed on to the focussing telescope, the size of the shank being such that it allows the telescope tube to rotate easily within it.

Variation in Optical Activity of Quartz.—The optical activity of quartz increases with the temperature, and is expressed, according to Jobin,[10] by the equation $a^t = a^o (1 + \cdot000146t)$, where a^t is the specific rotation at t, and a^o that at a lower temperature. Hence, if a quartz wedge compensating polariscope, adjusted at the standard European temperature of 20° C., be used in the tropics at a temperature of 30° C., a *less* thickness of quartz will be required to compensate for the rotation of a sugar solution. This error is small but still appreciable. Suppose at 30° C. a reading of 96·0 be observed, then at 20° C. the reading would be 96 $(1 + \cdot000146 \times 10)$ $= 96.14$.
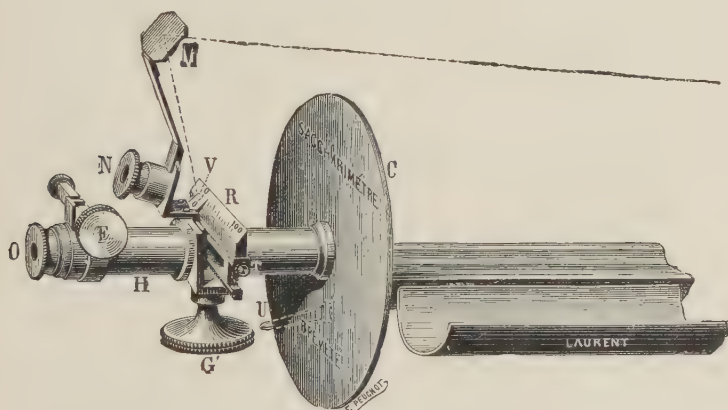
FIG. 247.

Similarly, a quartz control plate standardized at 20° C. will give the same reading at 30° C. in a quartz wedge compensating instrument, but will give a higher reading at the higher temperature in an instrument compensating by rotation of the analyser.

Polariscope Tubes.—The older form of polariscope tube is shown in *Fig. 249*. It consists of a glass or metal tube, the ends of which are ground exactly flush. In filling a tube with a solution for observation a glass disc is placed on one end and secured in position by screwing on a metal cap. The tube is held vertical and the solution is poured in until it fills the tube, and rises by capillarity over the upper surface; a second glass disc is then slid on and secured in position by a metal cap.

In the later, more convenient form of tube, *Fig. 250*, the discs are held in position by spring metal caps. The Laurent instruments use a bayonet spring catch. The objection to the use of screw metal caps is the danger of producing a strain in the glass discs, whereby they themselves become optically active.

Pellet's Continuous Tube.[11]—This consists of a tube, *Fig. 251*, provided with a syphon overflow. The solution under analysis is contained in the beaker *a*; on opening the spring clip *b** the solution already in the tube is displaced and its place is taken by that flowing in from the beaker *a*. Until all the material originally in the tube is dis-

Fig. 248.

placed by that entering, a reading cannot be obtained, due to the formation of striæ. By arranging a wire cradle connected to and alongside of the trough of the polariscope, the Pellet tube can be rolled out if it is desired to introduce another tube. The Pellet tube effects a great saving of time when many consecutive analyses have to be performed, in fact it is hard to say why every sugar laboratory does not use this device.
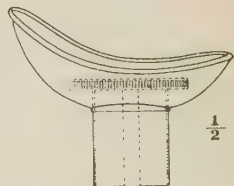
Fig. 249.

Water Jacketed Tube.—In the Clerget analysis, where the control of the temperature is of importance, the tube shown in *Fig. 252* is convenient; it is filled through the aperture in the middle after both of the end caps have been placed in position; a thermometer is inserted through the same aperture to take the temperature of the solution. A continuous current of water may, if necessary, be made to flow through the jacket, and readings at an elevated temperature obtained.

Fig. 250.

Value of Scale Degree.—In polariscopes the scale is divided into 100 equal parts on the assumption that the rotation of cane sugar is independent of concentration. The following table gives the value of each degree of the polariscope scale calculated from the Schmitz determinations of the rotation of cane sugar at varying concentration, and in refined analyses

---

*This clip is more conveniently placed on the delivery tube and resting on the table.

these factors should be used in place of the normal weight, taken here as 26 grms. per 100 true cc. : —

Polariscope reading in 20 cm. tube.		Corrected Normal Weight.		Polariscope reading in 20 cm. tube.		Corrected Normal Weight.
5	. . . .	25·90	. . . .	55	. . . .	25·96
10	. . . .	25·92	. . . .	60	. . . .	25·97
15	. . . .	25·93	. . . .	65	. . . .	25·97
20	. . . .	25·94	. . . .	70	. . . .	25·97
25	. . . .	25·94	. . . .	75	. . .	25·98
30	. . . .	25·94	. . .	80	. . . .	25·98
35	. . .	25·95	. . .	85	. . . .	25·99
40	. . . .	25·95	. . . .	90	. . . .	25·99
45	. . . .	25·95	. . . .	95	. . . .	25·99
50	. . . .	25·96	. . .	100	. . . .	26·00

Control of Scale.—Quartz plates, the exact value of which has been determined in sugar degrees, may be obtained from makers. These plates are standardized at 20°C. in Europe, and as they are equally affected by variation of temperature with the quartz wedge they will serve at any
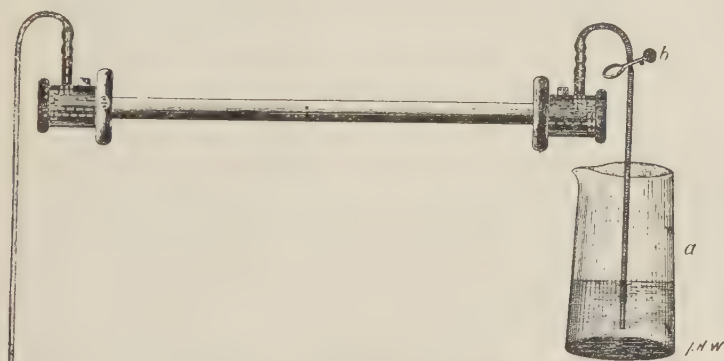
FIG. 251.

temperature to control the scale of a polariscope of this type ; but if used to control the scale of a polariscope compensating by rotation of the analyser, the correction for temperature must be applied.

A control observation tube by Schmidt and Haensch is shown in *Fig. 253*; it consists of an outer tube, *T*, in which is moved by means of a rack and pinion gear the tube *f*, fitting closely into *T*, exit of liquid between *T* and *f* being prevented by the washer *e ;* the tube *f* is closed by a glass disc at *c*. The solution to be used for testing is poured into the funnel *a*, whence it fills the tube *T*. The distance between *d* and *e* is regulated by the rack and pinion gear, the exact distance and also the length of the column of liquid being read off a scale carrying a vernier ; the tube is conveniently filled with a solution of the normal weight of sugar in 100 cc. ; with a column of liquid 20 cm. long a reading of 100 should be obtained, and other readings should be proportional to the length of the column of liquid. A very rapid control over

the scale can thus be obtained; of course the scale can also be tested by polarizing different weights of pure sugar in a tube of constant length, but this, compared with the adjustable control tube, is a laborious operation.

It is a principle in analysis that every piece of apparatus should be standardized twice, once by the maker and once by the user. The method
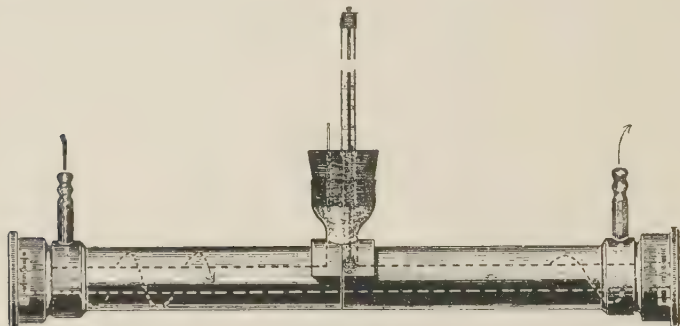
FIG. 252.

employed by Harrison[12] in the British Guiana Goverment Laboratory is as follows:—

"Each 100 cc. flask in use for sugar polarization is verified by weighing into it 99·533 grms. of recently boiled distilled water at 28°C. The exact weight of chemically pure sugar, which when made up to a bulk of 100 cc. in one of the corrected flasks at 28°C. gives a polarization reading of 100°, is ascertained by experiment for each instrument, and this weight of sugar is invariably used instead of the maker's normal weight for 17·5°C."
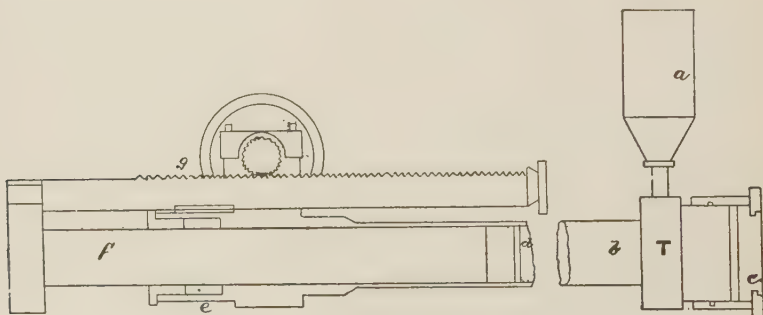
FIG. 253.

Double Wedge Compensator.—Two sliding wedge compensators are fitted to the instrument; the milled head controlling one is coloured black, and the other red; the observation is made in the usual way with the black compensator; the active solution under analysis is then removed and neutrality obtained by adjusting the red compensator; the readings on the red and black scales should be identical, practically demonstrating the accuracy of the reading, for it is very unlikely that an identical error should be made twice

running, or that both compensators should possess the same error in construction. The arrangement of the wedges is shown in *Fig. 254.*

Saccharimeters are usually only provided with a scale reading to $-30°$; with this device, by setting the zero of the red scale to the right, minus readings of any value can be obtained.

Use of Light Filter with Quartz Wedge Compensation.

—The application of the quartz wedge to compensate for the rotation of sugar solutions is only possible because of the near coincidence of the rotation dispersion of cane sugar and of quartz; actually, the violet rays are a source of error, and these may be shut off by passing the light through a crystal, or through a dilute solution, of potassium bichromate. With dilute solutions the effect of the violet rays is barely appreciable, but they become noticeable (destroying the sensitiveness of the end point) at readings near the 100 point. Some instruments are provided with a cell to be placed between the lamp and the polarizer, which is filled with a dilute solution of potassium bichromate, and in other patterns a plate of bichromate is inserted in the ocular of the focussing telescope. This light filter should always be used when the incandescent gas or acetylene light is used.

The disturbing effect of the violet rays is especially noticeable when solutions of glucose are being observed.
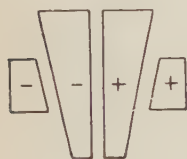
FIG. 254.

Adjustment of the Polariscope. — *Zero Adjustment.* —

After having obtained the end position with no active material in the body of the instrument, the scale should read zero. If another reading is obtained, the scale can be adjusted to zero by rotating a square headed pin located in the Schmidt & Haensch and Peter's instruments at the side of the dust proof casing of the compensator; in the Fric instruments this pin is placed on the top of the dust proof casing. A key fitting the pin is supplied with the instrument.

Analyser Adjustment.—In case a sharp end point cannot be found the analyser must be adjusted. In the earlier instruments, underneath the barrel containing the analyser, will be seen a pin; this pin carries a worm gearing with a wheel cut on the sleeve containing the analyser; rotation of this pin by means of the key mentioned above controls the position of the analyser, the best position of which must be found by trial and error.

In other instruments, on each side of the tube containing the analyser, will be found two screws with projecting heads. These screws have conical points bearing eccentrically on the edges of two holes bored in the rotating sleeve carrying the analyser. To adjust, both screws are loosened and one screw is slightly turned, the end point is then found by altering the position of the quartz wedges. If a sharper end point is found the screw has

been turned the right way, and by trial and error the sharpest end point is found; after it has been determined the screw which was *not* used in the adjustment is tightened until it just bears on the sleeve, after which the second screw is turned home; the scale adjustment to zero is then made.

In other instruments the analyser is held in a brass tube which rotates easily within an outer tube forming the casing of the instrument; on the casing is formed a slot covered by a collar; two pins pass through the collar and slot and screw into the tube which carries the analyser; by loosening the screws the analyser can be rotated about its longitudinal axis through the length of the slot.

Polarizer Adjustment.—The instruments employing the Jellet prism have the polarizer fixed in position; the instruments employing the Lippich polarizer are capable of adjustment in both polarizer and half prism; the former is capable of rotation by the last-mentioned device above. The half prism is usually capable of two adjustments laterally by means of three screws which pass through the casing; two of these screws pass into the holder of the half prism, and one bears on the holder; rotation of the half prism is effected by a system of screws and slots substantially as described above.

In the Schmidt & Haensch triple shade instrument one of the half prisms is capable of adjustment by means of coned screws bearing eccentrically on the holder of a half prism; adjustment is made by trial and error as described for the analyser; this adjustment is necessary when the outer portions of the triple field are unequally in shadow.

Adjustment of the prisms is a delicate operation and should only be undertaken when absolutely necessary, but no damage need be anticipated when the theory of the instrument is understood and when care and patience are used. If an old disused instrument is available, it is better first to acquire familiarity with the construction from manipulation of its parts.

REFERENCES IN CHAPTER XXI.

1. This chapter is based on Landholt's classical treatise: "*The optical Rotation of Organic Substances.*"
2. *Ann. Chem. Phys.*, 1840, p. 401.
3. *Brit. Assoc. Report*, 1860, p. 13.
4. *Bull. Soc. Chem.*, 1870, p. 140.
5. *Zeits. für Instrum.*, 2, 167; 14, 326.
6. Dingler's *Poly. Jour.*, 1897, p. 608.
7. *Bull. Assoc.*, 19, p. 101.
8. *Ueber ein neues Polaristrobometer.* Bern, 1865.
9. *I. S. J.*, 108.
10. *Zeit. für Rub. Ind.*, 1898, p. 835.
11. *Zeits. für Rub. Ind.*, 1891, 338.
12. *Jour. Roy. Agric. Com. Soc. Brit. Guiana*, December, 1895.

CHAPTER XXII.

THE OPTICAL ASSAY OF SUGARS.

The optical assay of sugar is based on the direct proportionality of the rotation of a ray of polarized light to the concentration of the solution, and to the length of the layer through which the polarized ray passes. Hence if the rotation of a ray of polarized light be measured for any known concentration and length of layer, determination of the rotation and length of the layer of the solution afford data to calculate the concentration; further, in case the material under examination is a solid, the solution of a known weight of the material in a definite volume and determination of the rotation under known conditions, give data to calculate the percentage of sugar in the material under examination.

The instruments used for this purpose are known as polariscopes, and are discussed in Chapter XXI.; in this Chapter the general principles of the process are outlined; their application to different products of the sugar house is developed in Chapter XXIII.

The Clearing Agents used.—In general sugar solutions are unfitted for polarimetric assay without the addition of some agent to precipitate colouring and other bodies, which render the solution turbid. The materials in general use are:—

1. *Alumina Cream.*—Solutions of high grade sugars are often sufficiently clear for polarimetric assay except for a slight turbidity which may be removed by agitation of the solution with a little alumina cream and subsequent filtration; alumina cream is prepared thus:—Precipitate a solution of an alum with a slight excess of ammonia; wash by decantation till all soluble matter is removed, and preserve as a thick cream.

2. *Precipitation of alumina within the solution.*[1]—The precipitation of alumina within the solution has a much greater decolourizing effect than the addition of alumina cream, and the effect is increased by the addition of very small quantities of hydrosulphites. As carried out by the writer the clarification is thus made: to a measured quantity of the solution under analysis a quantity of a solution of sodium aluminate is added, and after mixture followed by an equivalent quantity of a saturated solution of aluminium sulphate and about ·05 grm. of sodium hydrosulphite. The aluminate and alum solutions are previously standardized against each other, using phenolphthalein as an indicator.

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With this method with sugars and juices a filtrate is obtained as much decolourized as by the use of basic lead acetate. Waste molasses cannot be satisfactorily observed in greater than ·25 normal solution.

Normal weights of sugars require from ·5 to 1 cc. of a saturated solution of alum, and molasses in ·25 normal weight, from 2 cc. to 3 cc.

3. *Basic Acetate of Lead* has formed the most general clarificant of sugars. It is used by adding a concentrated solution to the solution of sugar under analysis. For 26 grms. of refining sugars from ·1 to 1 cc. of lead acetate solution, sp. gr. 1·25, are necessary ; for the same quantity of molasses up to 15 cc., and for 100 cc. of juice up to 6 cc. An excess of lead acetate must not be used. The material is thus prepared : 264 grms. litharge are digested with 440 grms. neutral acetate of lead until dissolved and made up to 2000 cc.

4. *Neutral Acetate of Lead* is used precisely as the basic acetate, but its use is limited to such products as are light-coloured.

5. *Calcium Hypochlorite* is used by Zamaron[2] in conjunction with neutral acetate of lead. 625 grms. of calcium hypochlorite are shaken with 1000 cc. of water, and the filtered solution, which should mark 18°- 20° Beaumé, preserved for use. Pellet uses 20 cc. of this in conjunction with neutral lead acetate to decolourize 4 grms. of molasses.

6. *Dry Basic Acetate of Lead.*—This material was introduced by Horne[3] to counteract certain errors occasioned by the use of a *solution* of lead acetate. The dry acetate, together with a little sand, is added to the solution of sugar after it has been made up to definite volume. For 26 grms. of sugar about 0·5 grm. of this material is required.

7. *Charcoal.*—Bone charcoal added to sugar solutions exercises a powerful decolourizing effect, but, as it at the same time absorbs an appreciable quantity of sugar, it is little used. It has been recommended to filter the sugar solution through charcoal and to collect separately the later runnings after the charcoal has absorbed all the sugar that it is capable of doing.

Basic Nitrate of Lead is recommended for use by Herles. Two solutions are used :—*a.* 2000 cc. water and 90 grms. caustic soda; *b.* 2000 cc. water and 1000 grms. lead nitrate. The lead solution is added to the alkali immediately before use in the proportion of 1 of lead to 1·0 to 1·1 of alkali. With this solution it is stated that the readings are not affected by an excess and that lead does not pass into solution. It has not come into any general use.

8. *Mercuric Compounds* exercise an effect similar to that of lead with the distinction that they precipitate amides from solution. They are not in general use in sugar analysis, but very recently Andersen[4] has recommended for use as a clarificant the following solution : 220 grms. HgO, dissolved in 160 cc. HNO_3, sp. gr. 1·39, and made up to 1000 cc. with the addition of

60 cc. of a 5 per cent. solution of caustic soda; the material after addition to the sugar solution is immediately neutralized. It is stated that an excess has no action on the opticity of the sugars.

The Effect of the Precipitate produced by Lead Compounds in Clarification.

—In the majority of the above detailed schemes for clarification an insoluble precipitate is formed which occupies an appreciable volume, so that if, after clarification, the solution be made up to 100 cc. the actual volume is 100 cc. less the volume occupied by the precipitate; *prima facie*, an error is thus introduced, though that this is the case is denied by certain chemists. H. Pellet[5] in particular claims that the precipitate formed by the addition of basic acetate of lead entrains sugar, and that this entrainment compensates for the volume occupied by the lead precipitate. In his experiments he shows that a weight of sugar material dissolved in water and made up to 100 cc. in the presence of its precipitate gives a reading of, say, 50°, the same weight of sugar material made up to 200 cc. in the presence of its precipitate will give a reading exactly half the first, in this case, 25°; if the lead precipitate exercised an influence proportional to its volume the first solution would be more than twice as concentrated as the second, and hence the first reading should be more than twice as large as the second; this phenomenon he attributes to the entrainment of sugar by the lead precipitate, and claims that it is unnecessary to apply a correction for its volume.

The writer in investigating the same subject found also that a fixed weight of sugar material made up to different volumes in the presence of the precipitate tends to give identical polarizations independent of the dilution, and explains the apparent non-influence of the lead precipitate by an *increase* in the specific rotation of cane products with dilution.

Horne's very detailed experiments[6] also point to the conclusion that the lead precipitate introduces a positive error and that sugar is not entrained.

Correction for the volume of the lead precipitate is made by the following methods :—

1. *Scheibler's Method.*[7]—The material under analysis is first made up to a volume of 100 cc. in the presence of its precipitate, and the reading taken; a second reading is taken under identical conditions, except that the volume is now made up to 200 cc.

Let x be the volume of the precipitate; let a be the reading in 100 apparent cc., and b the reading in 200 apparent cc.

Then $(100 - x) a = (200 - x) b$.

Solving this equation x is found.

Assuming that there is a change in the rotation of cane products with dilution this method is inaccurate, and the writer modifies it thus:

The material under analysis is first made up to 100 cc. in the presence of its precipitate, filtered, and 50 cc. of the filtrate diluted to 200 cc., and the reading observed; let it be a. The same weight of material is made up to 200 cc. in the presence of its precipitate, and the reading taken; let it be b; let the volume of the precipitate be x; the two readings to be observed are now almost exactly at the same dilution; then $2a(100 - x) = (200 - x)b$.

Solving this equation x is found.

2. *Method of Sachs.*[8]— The precipitate obtained is collected on a filter and washed until free from sugar; it is then transferred to a graduated flask into which is weighed a sugar of known polarization. This weight of sugar is then made up to an apparent definite volume in the presence of the precipitate and a polarimetric reading taken. The apparent increase in the polarization of the sugar affords data to calculate the volume of the precipitate.

3. *Wiechmann's Method.*[9]—The precipitate is collected, washed free of sugar, dried and weighed. Its specific gravity is then obtained with the pycnometer, benzene being the liquid used; from its weight and density the volume of the precipitate is calculated.

4. *Horne's Method.*[10]—Horne eliminates the error due to the volume of the lead precipitate by making the solution of sugar product up to definite volume, and clarifying by the addition of dry basic acetate of lead in powdered form, and assuming that the volume of the acetic radical which goes into solution is compensated by the volume of the material precipitated. This method has met with considerable approval.

The Presence of Active Bodies other than Sugar.—The active bodies other than cane sugar present in cane products are chiefly dextrose and levulose; mannose and raffinose in small quantities have also been reported, and small quantities of gums are also present. The disturbing influence of dextrose and levulose is removed by the Clerget method, and the other bodies are generally present in such small quantities as to be negligible.

The Effect of Lead Acetate on the Opticity of Sugar.— The effect of lead acetate on cane sugar is small, and is given by Bates and Blake[11] as under, pure sugar being tested in normal concentration

Basic lead acetate added. cc.		Difference in Polarization. Ventzke°.		Basic lead acetate added. cc.		Difference in Polarization. Ventzke°.
·5	..	—0·09	..	4·0	..	—0·06
1·0	..	—0·13	..	5·0	.	—0·93
1·5	..	—0·10	..	6·0	..	—0·00
2·0	..	—0·13	..	7·0	..	+0·05
2·5	..	—0·06	..	8·0	..	+0·09
3·0	..	—0·08	..	10·00	..	+0·19

The Effect of Concentration on the Rotation of Sugars.—
The rotation of cane sugar is but little affected by dilution ; there is, however, a sensible rise in the specific rotation with dilution.

The results of Schmitz[12] (which are those most often quoted) and of Nasini and Villavecchia[13] are in close agreement. If p is the percentage of sugar, and c the concentration in grms. per 100 cc., then, according to Schmitz,

$$p = 5 - 65 ; \quad [a]\frac{20}{D} = 66{\cdot}510 + {\cdot}004508p - {\cdot}00028052p^2$$

$$c = 2{\cdot}5 \text{ to } 28 ; \quad [a]\frac{20}{D} = 66{\cdot}639 - {\cdot}020820c + {\cdot}00034603p^2$$

and approximately, for purposes of calculation,

$$c = 2{\cdot}5 \text{ to } 28 ; \quad [a]\frac{20}{D} = 66{\cdot}541 - {\cdot}008415c.$$

Nasini and Villavecchia found

$$p = 3 \text{ to } 65 ; \quad [a]\frac{20}{D} = 66{\cdot}438 + 010312p - {\cdot}00035449p^2.$$

In very dilute solutions the results of investigators are contradictory. Tollens[14] found quite irregular values, Pribram[15] found a decrease in falling from $p = 3{\cdot}659$ to $\cdot222$, whilst Nasini and Villavecchia found an increase in falling from $p = 1{\cdot}253$ to $\cdot824$.

The specific rotation of dextrose increases with concentration, and is thus expressed by Tollens[16] for the anhydrous body

$$[a]\frac{20}{D} = 52{\cdot}50 + {\cdot}018796p + {\cdot}0005168p^2.$$

The rotation of levulose also decreases with dilution. Hönig and Jesser[17] give the formula for $c = 60$ to 95 per cent.

$$[a]\frac{20}{D} = -113{\cdot}96 + {\cdot}258c,$$

c being the percentage of water in the solution. This reduces to

$$[a]\frac{20}{D} = -(88{\cdot}16 + {\cdot}258p).$$

Ost found the effect of dilution to be expressed by the formula

$$[a]\frac{20}{D} = -(91{\cdot}90 + {\cdot}111p) \text{ for values of } p \text{ 1 to 30 per cent.}$$

The Effect of Temperature on the Rotation of Sugars.—
The effect of temperature, having a very considerable bearing on the valuation of sugars, has been much studied, and very discordant results have been recorded. A very complete bibliography of the question is given by Wiechmann.[18] With very few exceptions it is now generally accepted that the rotation of cane sugar decreases with rise in temperature. Watts and Tempany[19] in a series of very careful experiments found this relation to hold

for quartz wedge compensating instruments, the correction including that known as Jobin's.

$$\text{True polarization} = (1 + \cdot00039t) \text{ observed polarization,}$$

where t is the difference between the temperature of observation and that at which the instrument was graduated in C°.

This result is in very close agreement with those obtained by Harrison and by Wiley.

The rotation of levulose falls very rapidly with temperature rise. Hönig and Jesser[17] give for $p = 9$ and $t = 13°C.$ to $40°C.$

$$[a]\frac{t}{D} = -103 \cdot 92 + \cdot671t$$

and for $p - 23 \cdot 5$ and $t - 9°C.$ to $45°C.$,

$$[a]\frac{t}{D} = -107 \cdot 65 + \cdot692t$$

Jungfleisch and Grimbert[20] combine temperature and concentration in the one formula

$$[a]\frac{t}{D} = -[101 \cdot 38 - \cdot56t + \cdot108(c - 10)]$$

c being the concentration in grms. per 100 cc.

There do not appear to be any results published connecting the temperature and rotation of dextrose.

The Effect of Inactive Bodies on the Rotation of Sugars.—A small decrease in the rotation of cane sugar is brought about by the simultaneous presence of any of the following bodies:

Hydrates of the alkalies and alkaline earths.

Chlorides, nitrates, sulphates, carbonates, phosphates, acetates and citrates of the alkalies.

Borax, magnesium sulphate.

Chlorides of the alkaline earths.

An increase is observed with formaldehyde.[21]

In the quantities in which these bodies occur in routine analyses the effect is very small.

In the presence of lead acetate the specific rotation of levulose decreases until it becomes dextro-rotatory, and in the presence of mineral acids it increases ($v.$ Clerget Process).

Bi-rotation.—The initial rotation of many of the sugars when freshly prepared is much higher than that after standing some time. After standing 24 hours a constant end rotation is obtained; it is also rapidly obtained on heating, and by the addition of certain bodies in minute proportion, $e.g.,$ ammonia.

Specific Rotation of Bodies other than Cane Sugar, Dextrose, and Levulose, occurring in Sugar Analysis.—

For convenience of reference some of these are here collected :—

Raffinose .. .. .. $[a]\frac{t}{D} = 104\cdot2$ $t = 20$ (t = temperature.)

Maltose .. .... $[a]\frac{t}{D} = 140\cdot375 - \cdot01837p - \cdot095t$

(p = per cent. of material.)

Isomaltose gallisin .. $c = 10\cdot60$ $[a]\frac{20}{j} = 82\cdot76$

$c = 27\cdot29$ $[a]\frac{20}{j} = 80\cdot10$

$c = 54\cdot58$ $[a]\frac{20}{j} = 77\cdot32$

Lactose .. .. .. $[a]\frac{t}{D} = 52\cdot5$ $t = 20$

Mannose .. .. .. $[a]\frac{t}{D} = 12\cdot96$ $t = 20$

Galactose .. . .. $[a]\frac{t}{D} = 83037 + \cdot199p - (\cdot276 - \cdot0025p)\,t,$

for $p = 5$ per cent. to 35 per cent., and $t = 4°$ C to 40° C.

Arabinose .. .... $[a]_D = 104\cdot4$ $c = 10$ $t = 18$

(c = concentration in grms. per 100 c.c.)

Xylose .. .. .. $[a]_D = 18\cdot095 + \cdot06986p$ $p = 3$ to 34

Dextran .. .... $[a]_D = 230$

Levulan .. .. .. $[a]_D = -221$ $t = 20$ $c = 5$ to 30

Xylan .. .. $[a]_D = 70$ to 85

Direct Polarization.—
The optically active constituents of the cane sugar factory consist essentially of cane sugar, of dextrose, of levulose, and of small amounts of other sugars ; in many cases the combined optical effect of the reducing sugars is small and may even altogether vanish, so that it is very general to calculate the result of the analysis as if cane sugar was the only active body present. Results so obtained are referred to as *sugar from direct polarization*. The effect of optically active bodies other than sugars can be eliminated by the Clerget process described in the next section.

The Determination of Sugar by Clerget's Process.—
A solution of cane sugar when heated with acids is quantitatively converted into equal parts of dextrose and of levulose, and a solution of cane sugar originally dextro-rotatory is after such treatment found to be levo-rotatory. Clerget observed that the two rotations bore a fixed ratio to each other when the conversion of the cane sugar into dextrose and levulose was performed under fixed conditions. His original process was as under[22] : 16·471 grms. of sugar were dissolved in water, transferred to a flask graduated at 100 and at

110 c.c., water added to the 100 mark and the volume completed to the 110 mark with strong hydrochloric acid. After mixture the flask was placed in a water bath and heated in such a way that at the end of fifteen minutes the temperature had risen to 68°. The flask was then removed, rapidly cooled, and its contents polarized in a tube 220 cm. in length to allow for dilution. Clerget found that a solution of 16·471 grms. of sugar per 100 c.c., which polarized 100° in his polariscope, gave at a temperature of 0° a reading to the left of 44°, the rotation decreasing ·5° for every 1° rise in temperature. Hence followed the formula $s = \dfrac{a-b}{144 - \cdot 5t}$ where s is the true percentage of sugar, and a and b are the readings before and after inversion referred to the same concentration, and t is the temperature of the observation.

This method of making the *inversion* is not now generally followed, the official German instructions due to Herzfeld being as under[23] :—

The half-normal weight (13·024 grms.) is taken and dissolved in a 100 c.c. flask in 70 c.c. of water, 5 c.c. of hydrochloric acid of 1·19 specific gravity is added, and the flask and its contents warmed to 67°—70°C. and maintained at that temperature for five minutes, at the expiration of which time the maximum left rotation is obtained ; the flask is then rapidly cooled, its contents completed to 100 c.c., and polarized at a temperature as close to 20°C. as possible. A rise of temperature above 70°C. or a prolonged heating invalidates the results, and in the use of this process the directions must be exactly followed.

Herzfeld found that the Clerget constant varied with the concentration of the sugar, and constructed the following table :—

Grms. Sugar per 100 c.c.				Constant.	Grms. Sugar per 100 c.c.				Constant.
1	..	..	..	141·85	11	..	..	..	142·52
2	..	.	..	141·91	12	..	..	..	142·59
3	..	..	..	141·98	13	..	..	..	142·66
4	..	..	..	142·05	14	..	..	..	142·73
5	..	..	.	142·12	15	..	..	..	142·79
6	..	..	..	142·18	16	..	..	..	142·86
7	..	..	.	142·25	17	..	..	..	142·93
8	.	..	.	142·32	18	..	..	..	143·00
9	..	..	..	142·39	19	..	..	..	143·07
10	..	..	..	142·46	20	..	..	..	143·13

For the half-normal weight the factor is 142·66, which is the now generally accepted Clerget constant. The variation can also be expressed in the formula $s = \dfrac{a-b}{141\cdot 84 + \dfrac{i}{20} - \dfrac{t}{2}}$ where i is the reading after inversion in the 200 cm. tube without any correction. It will be observed that the constant here given varies much from that found originally by Clerget. In the

original Clerget process the concentration of the acid and of the sugar is greater than it is in that due to Herzfeld, and since the levo-rotation of levulose increases with concentration and with increasing strength of acid, a higher value for the constant is obtained. This point is of extreme importance and is one which is perhaps not uncommonly overlooked.

Of greater importance than the concentration of the acid is the temperature factor; the temperature should be observed at the moment of making a reading, the water-jacketed tube referred to in the previous Chapter being used.

Irregularities in the Clerget Process and Colour of Solution after Inversion.

—In certain cases, especially with low grade molasses, the solution becomes so dark coloured after inversion that it can only be read with great error or in a state of high dilution ; this inconvenience may be overcome thus.

a. To the solution after inversion a little bone charcoal is added, the whole shaken and filtered ; absorption of the reducing sugars does not occur.

b. To the solution as it cools is added a crystal of sodium sulphite ; the sulphur dioxide generated decolourizes the solution.

c. To the solution as it cools a little zinc dust is added, the decolouration being now due to the nascent hydrogen evolved.

Effect of Lead.—In the presence of basic lead acetate the left handed rotation of levulose decreases, the normal value being restored on neutralization. Hence, as has been shown in particular by Tervooren,[30] the direct reading should be taken after acidification of the filtrate after clarification with basic lead acetate. Tervooren's routine for eliminating the error in the analysis of molasses is—

"Dissolve $35 \cdot 816$ ($26 \cdot 048 \times \frac{1}{2} \times \frac{5}{2} \times \frac{11}{10}$) grms. molasses in 250 cc. water, with the addition of 40 cc. basic lead acetate ; receive 100 cc. of the filtrate in a 100–110 cc. flask ; add 1 cc. of 30 per cent. acetic acid and 2 cc. of alumina cream, make up to 100 cc., then filter and polarize. The reading multiplied by 2 is the direct reading."

Increase in Rotation of Levulose.—In the presence of hydrochloric acid the gyrodynat of levulose increases ; hence when levulose is initially present, a positive error is introduced. Browne[24] states that this error is corrected for by deducting from the percentage of sugar $\cdot 36$ per cent. for every 1 per cent. of levulose present, when 10 c.c. of hydrochloric acid, sp. gr. $1 \cdot 18$, are used per 100 c.c. of sugar solution.

Modifications of the Clerget Process.

—Various agents other than hydrochloric acid have been used to effect the inversion, such as oxalic acid, employed in the proportion of one part per 100 of sugar at a temperature of 50°C.—60°C. for several hours. Yeast as an agent was first used by O'Sullivan and Thomson[25] as follows :—50 c.c. of the solution under analysis are raised to a temperature of 55°C. ; some brewers' yeast in quantity $\frac{1}{10}$

that of the sugar present is pressed in a towel, placed in the flask, the contents of the flask well stirred and kept at 55°C. for four hours; clarification is effected by alumina cream, and the whole, after making up to 100 c.c., filtered and polarized.

In all modifications of the official Clerget process it must be remembered that a constant differing from the official one obtains, and that must be determined experimentally under the same conditions as those under which an analysis is made.

The Separation of Sugars occurring in Mixtures.—The estimation of cane sugar in the presence of levulose and of dextrose is performed under the Clerget process; the estimation and separation of the accompanying reducing sugars is thus obtained after Browne[24] :—

1. The reducing power of the sugars is expressed in terms of dextrose, the reducing power of which is put equal to unity. The reducing power of the commoner sugars investigated by Browne is given in Chapter XXIII.

2. The optical rotation of the sugars is expressed in terms of cane sugar, the rotation of which is put equal to unity. According to Browne[2] these are—

Cane Sugar	1·000
Dextrose	·793
Galactose	1·21
Arabinose	1·571
Xylose	·283

Levulose.—The rotation varies so much with temperature that special numbers have to be calculated for each temperature. The factors calculated from the formula of Jungfleisch and Grimbert[20] are—

Temperature.	Concentration.						
	1 per cent.	2 per cent.	3 per cent.	4 per cent.	5 per cent.	10 per cent.	25 per cent.
15 ..	—1·384 ..	—1·385 ..	—1·387 ..	—1·389 ..	—1·390 ..	—1·398 ..	—1·422
20 ..	—1·341 ..	—1·343 ..	—1·345 ..	—1·346 ..	—1·348 ..	—1·356 ..	—1·380
25 ..	—1·299 ..	—1·301 ..	—1·303 ..	—1·304 ..	—1·306 ..	—1·314 ..	—1·338
30 ..	—1·257 ..	—1·259 ..	—1·261 ..	—1·262 ..	—1·264 ..	—1·272 ..	—1·296

Let x = per cent. of a given sugar A.

Let y = per cent. of a given sugar B.

Let a = dextrose ratio of sugar A.

Let b = dextrose ratio of sugar B.

Let R = per cent. of reducing sugars as dextrose.

Then $ax + by = R$ .. .. (1)

Let a = polarization factor of sugar A.

Let β = polarization factor of sugar B.

Let P = polarization of mixture, *i.e.*, reading in Ventzke scale in 20 cm. tube for 26 grms. of sugar in 100 c.c.

Then $a x + \beta y = P$ .. .. (2)

Solving these two equations the amounts of the sugars are found.

The difference between direct polarization and the polarization due to Clerget's process is the polarization of the dextrose and levulose in the mixture ; the dextrose and levulose are then separated according to the equations above.

The simultaneous Determination of Cane Sugar and Raffinose.—The official German method due to Creydt[26] is as follows :—

The direct reading is taken at 20° C.

The material is inverted according to the official Clerget process.

Let A = direct reading, B = reading after inversion, c = algebraic difference between A and B.

Then

$$\text{Sugar per cent.} = \frac{C - \cdot 493A}{\cdot 81}$$

$$\text{Raffinose per cent.} = \frac{A - S}{1 \cdot 54}$$

Pieraert's process is as follows[27] :—

10 grms. of material are dissolved in 100 c.c. ; this solution serves to give the direct reading.   50 c.c. of this solution are transferred to a 100 c.c. flask, to which are added 10 c.c. of a 20 per cent. solution of citric acid, and the mixture boiled for 15 minutes in a flask to which is attached a reflux condenser ; after making up to 100 c.c. and cooling, the inverted reading is taken.   Then if x and y are quantities of cane sugar and of hydrated raffinose in 100 c.c. of solution, and a and b are the readings before and after inversion,

$$x = 9 \cdot 287a - 18 \cdot 311b$$
$$y = 3 \cdot 659a + 11 \cdot 652b$$

The simultaneous Determination of Cane Sugar, Invert Sugar, and Raffinose.—The following scheme is due to Wortmann[28] :—

The reducing sugars are determined under Clerget's process, and calculated according to the formula—

$$R = \frac{47C}{q}$$

R being the per cent. reducing sugars, C the weight of copper, and q the quantity of material used.

The direct and invert readings are then obtained according to the official German method.

Then

$$\text{Per cent. cane sugar} = \frac{\cdot 9598A - 1 \cdot 85B - \cdot 277R}{1 \cdot 5648}$$

$$\text{Per cent. raffinose} = \frac{A - S + \cdot 3103N}{1 \cdot 85}$$

where A and B are the direct and invert readings.

The Effect of Temperature on the Polarization of Sugars.—Although there is no doubt that the rotation of cane sugar falls with a rise in temperature, in commercial sugars other factors are at work. Browne[29] has conclusively shown that owing to the presence of levulose in low grade sugars a rise in temperature is often accompanied by a rise in polarization, and that the application of a temperature correction is invalid; to obtain a just 'polarization' all sugars should be polarized at one standard temperature, which is in the United States fixed at 20°C. It is extremely unfortunate that the Supreme Court of the United States has definitely settled that legally the polarization of a sugar is the percentage of sucrose in that sugar, and has also established the validity of temperature corrections, entirely losing sight of the presence in commercial sugars of active bodies other than sucrose. The polarization of a sugar is a useful trade convention but analytically has no real meaning.

REFERENCES IN CHAPTER XXII.

1. *I. S. J.*, 92, 99.
2. *Bull. Assoc. 16*, 337.
3. *J. A. C. S.*, *26*, 186.
4. *Abs. in Jour. Soc. Chem. Ind.*, 1909, 805.
5. *I. S. J.*, 93.
6. *J. A. C. S.*, 1907, 926.
7. *Zeits. für. Rub.*, 1875, 1054.
8. *Revue. Universelle de la Fabric de Sucre*, *1*, 451.
9. *I. S. J.*, 56.
10. *I. S. J.*, 61.
11. *Bull. U. S. Bur. Standards*, *3*, 105.
12. *Ber. Deut. Chem. Gesel.*, *10*, 1414.
13. *Pub. Lab. Chem. Cen. Della. Gab. Roma.*, 1891, 47.
14. *Ber. Deut. Chem. Gesel.*, *10*, 1410; *17*, 1757.
15. *Ber. Deut. Chem. Gesel.*, *20*, 1848.
16. *Ber. Deut. Chem. Gesel.*, *24*, 2000.
17. *Zeits. für Rub.*, 1888, 1028.
18. *I. S. J.*, 21.
19. *W. I. B.*, *6*, 52; *7*, 152.
20. *Comptes rendus*, *107*, 390.
21. *Chem. Centralblatt*, 1907, p. 1320.
22. *An. Chem. Phys.*, 1849, p. 185.
23. *Zeit. Ver. Deut. Rub. Ind.*, *28*, 699.
24. *Jour. Am. Chem. Soc.*, *28*, 4.
25. *Trans. Chem. Soc.*, 1891, p. 46.
26. *Zeit. für Rub. Ind.*, *38*, 867.
27. *Bull. Assoc.*, *23*, 1143.
28. *Zeit. für Rub. Ind.*, *39*, 766.
29. *Am. Sug. Ind.*, XI., 176.
30. *Arch.*, 1904, 321.

CHAPTER XXIII.

THE DETERMINATION OF REDUCING SUGARS.

Solutions of dextrose and other hexose sugars when boiled with an alkaline solution of a cupric salt reduce the latter to the cuprous state in the form of cuprous oxide. Approximately two molecules of dextrose reduce five molecules of a cupric salt, but the quantities reduced vary with the conditions of experiment. Tables connecting the amount of copper contained and the amount of reducing sugar have been constructed by a number of experimenters. The method of Allihn[1] is that generally adopted, and is as follows —:*

Allihn's Method.—The solutions used are :—

A. 34·64 grms. copper sulphate in 500 c.c.

B. 173 grms. potassium sodium tartrate and 125 grms. caustic potash in 500 c.c.

Thirty c.c. of each solution are mixed, 60 cc. of water added, and the whole brought to the boiling point over a direct flame; twenty-five cc. of the reducing sugar solution are then run in, the whole again brought to the boiling point, and the boiling continued for two minutes; an equal volume of cold water is then added and the reduced copper determined by one or other of the methods given below, whence the amount of reducing sugar is obtained from reference to the tables in the *Appendix.*

The Filtration of the Cuprous Oxide.—*A.* If filtration over reduced pressure is not available paper must be used; the reduced copper oxide passes very readily through paper, and only paper of close texture can be used. The paper always absorbs and retains copper sulphate, and the amount must be determined by a blank experiment.

B. The Soxhlet tube, *Fig. 255,* very often used, consists of a glass tube about six inches long in all; the upper portion is about three inches long and half an inch in diameter, and terminates in a concave bottom to which is attached a short capillary of about $\frac{1}{32}$ in. bore; the lower half is about three inches long and in diameter tapers from half to $\frac{3}{16}$ in. It is prepared for use

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* Munson and Walker's method substitutes caustic soda for potash and a two for a four minute boiling; I give Allihn's method since it still remains official in the U.S. : it is moreover used by Browne whose scheme is the only one completely accounting for all the factors in the assay of complex sugar mixtures; Browne's check analyses by Allihn's method leave nothing to be desired on the grounds of accuracy. (N.D.)

thus :—A plug of glass wool is placed on the concave bottom of the tube and above this a pad of asbestos ; the plug of glass wool should be about $\frac{3}{8}$ in. deep and the asbestos about $\frac{1}{16}$; the best quality of asbestos must be used and
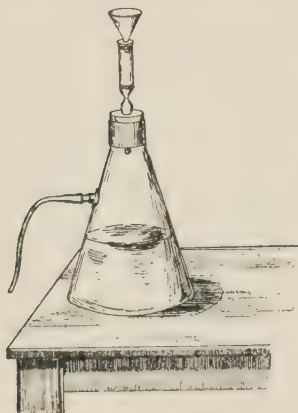
previous to use it should be digested, first in caustic soda, then in nitric acid, and finally in water. After the Soxhlet tube has been prepared, it is fitted into the stopper of the filter flask and filled about three parts full with water ; a small funnel is then fitted on to the tube, the stem of which does not quite reach to the level of the water in the tube ; the funnel is then filled with water and the pump started ; as the water passes through the filter, the liquid undergoing filtration is poured into the funnel, care being taken to keep the funnel full ; when all the copper oxide has been brought into the funnel, the level of liquid is maintained by

Fig. 255.

hot water until all the precipitate has passed into the Soxhlet tube and is continued until the washing is complete.

C. A Gooch crucible consists of a tall crucible of conventional pattern, the bottom of which is a perforated disc ; it is prepared for use as described for the Soxhlet tube, save that the pad of glass wool is unnecessary.

The filtration apparatus used in the laboratories of the Hawaiian Sugar Planters' Association is shewn in *Fig. 256* ; the filter flask is of the form due to Diamond. The tube *a* communicates with the vacuum pump ; connection with the atmosphere may be made by the cock on the tube *b* ; the Gooch crucible *c* is held in the carbon tube *d*, a tight joint being made by a piece of inner tubing of a bicycle tyre ; the filtrate may be discharged through *e*. The advantages of this apparatus for all vacuum filtrations are obvious.
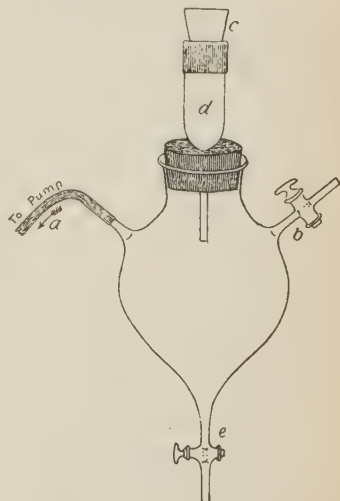
Fig. 256

The Determination of the Reduced Copper.—A. *As Cuprous Oxide.*

The cuprous oxide after collection by one or other of the above methods is dried to constant weight, preferably in a vacuum oven, or else at 105°C. The drying is materially accelerated by washing the precipitate first with alcohol and then with ether.

B. *As Cupric Oxide.*—If the cuprous oxide has been collected on paper the precipitate is, after drying, detached as completely as possible from the

paper and ignited in a porcelain crucible; the paper and adhering cuprous oxide are burnt separately, the cuprous oxide being partly reduced to copper; the ash and reduced copper are placed in the crucible, a few drops of nitric acid added, evaporated to dryness and cautiously ignited. If collected in a Soxhlet tube the narrow end of the tube is connected by rubber tubing to a vacuum pump and a current of air is sucked through the layer of cuprous oxide; at the same time the tube is heated over a small flame; the cuprous oxide is seen to glow and is rapidly converted into cupric oxide. If a Gooch crucible has been used, it and its contents are heated at a low red heat, care being taken to prevent the reducing gases of the flame entering the crucible, an end which is best obtained by placing the crucible containing the cuprous oxide inside a second one.

C.—As Copper, by Reduction in Hydrogen.—The precipitate of cuprous oxide conveniently collected in a Soxhlet tube is attached to an apparatus generating hydrogen, and a current of hydrogen is passed through the tube. On gently heating the tube the cuprous oxide is rapidly reduced to metallic copper.

According to Perrault[2] the hydrogen should be purified by being passed through towers containing—

a. Crystals of iodine, mixed with pumice stone.

b. Caustic soda.

c. Potassium permanganate 5 per cent., in caustic soda of density 1·32.

d. Potassium bichromate in concentrated sulphuric acid.

FIG. 257.

D.—By Electrolytic Deposition.—In the United States Agricultural Department's laboratory the copper is obtained by electric deposition; the cuprous oxide is dissolved in nitric acid and collected in a platinum basin of about 175 c.c. capacity; after the addition of 3-4 c.c. sulphuric acid the copper is ready for deposition, which is thus effected by Spencer.[3]

"Where a direct current is used in lighting the sugar-house, it is the most convenient source of electricity for depositing the copper. The current must be passed through a resistance or regulator in addition to the lamp. A convenient and durable regulator is shown in *Fig. 257*; c is a glass tube partly filled with water slightly acidulated with sulphuric acid; the wire a connects with a platinum sealed into the tube; b s a glass tube through which a copper wire extends and connects with a platinum wire e sealed into this tube. The tube b may be slipped up and down, thus regulating the distance between the wires e and a and regulating the current. The twin wire m is separated, severed, and one end d connected with the platinum dish in which the copper is to be deposited and the other with the

regulator b, thence through the acidulated water, and a with the platinum cylinder suspended in the copper solution. Sufficient current for a large number of dishes arranged in sets of four will pass through a 16 C.P. or 32 C.P. lamp. The copper should be deposited very slowly. Usually, if the apparatus be connected when the lights are turned on in the evening, all the copper will be deposited before they are turned off in the morning."

E. By the Permanganate Process.[4]—In this process the cuprous oxide is dissolved in a concentrated solution of ferric sulphate in 25 per cent. sulphuric acid; the ferric oxide is reduced by the cuprous oxide under the equation

$$5\,Cu_2O + 5\,Fe_2(SO_4)_3 + 5\,H_2SO_4 = 10\,CuSO_4 + 10\,FeSO_4 + 5\,H_2O$$
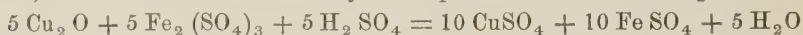
and the ferrous sulphate formed is estimated by titration with potassium permanganate.

The exact copper value of the permanganate should be determined by direct assay against a pure preparation of a copper salt.

A solution of a ferric salt will always decolourize a few drops of decinormal permanganate, and hence a fixed quantity of the ferric solution should be adhered to; by standardizing the permanganate under the conditions of the subsequent assays this source of error is automatically removed.

F. Sidersky's Process.[5]—In Sidersky's method the precipitated cuprous oxide is dissolved in a measured quantity of standardized sulphuric acid to which a little potassium chlorate has been added. The reaction proceeds as follows:—

$$3\,Cu_2O + 6\,H_2SO_4 + KClO_3 = 6\,CuSO_4 + KCl + 6\,H_2O.$$
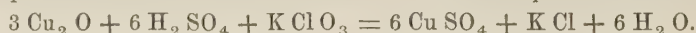
The excess of sulphuric acid is then titrated with standard alkali, or an excess of standard alkali may be added and titrated back with standard sulphuric acid; in the presence of free ammonia the solution is blue changing to green when all the ammonia is saturated. It is advised that half normal ammonia be employed. The amphotère in this method appears to the writer's eye inconveniently large, the change from blue to green not being at all sharp. The ammonia and sulphuric acid solutions should be standardized against each other, using 2 c.c. of a concentrated solution of copper sulphate as an indicator.

G. Iodometric Process.—The reactions involved are

$$2\,Cu(CH_3COO)_2 + 4\,KI = CuI + 4\,KCH_3COO + I_2$$
$$2\,Na_2S_2O_3 + I_2 = 2\,NaS_2O_3 + 2\,NaI$$
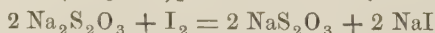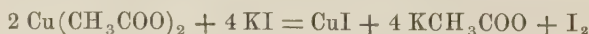
From the above equations it follows that 126·8 parts of iodine are equivalent to 63·5 parts of copper.

The precipitated cuprous oxide is dissolved in nitric acid, the excess of acid partly removed by evaporation, neutralized with a slight excess of sodium carbonate, and the precipitate redissolved with acetic acid. A slight excess of potassium iodine over that indicated as necessary from the above equation is added, and the iodine determined in the usual way with sodium thiosulphate, using starch as an indicator.

The thiosulphate solution should be standardized against pure electrolytic copper or a pure preparation of a copper salt.

Reduction Process employing Prolonged Heating.— There are not wanting objections to a boiling of the copper and glucose solutions for a short period, and processes involving the keeping of the materials for up to 15 minutes on a water bath have been proposed. These processes have never been so generally adopted as have those entailing a boiling of short period, and Munson and Walker[7] in particular have shown that serious error due to surface oxidation is thereby introduced.

Dextrose Ratio of Reducing Sugars.—The tables of Allihn give the equivalence between copper and dextrose; the methods described and the tables are equally applicable to all reducing sugars, as Browne[5] has shown that the relative reducing powers of the different reducing sugars are constant. The dextrose ratio of levulose is given by Browne as ·915, *i.e.*, where a certain weight of dextrose reduces one part of copper, the same weight of levulose will reduce ·915 part of copper, hence if levulose is being determined, the analysis is made exactly as if for dextrose, the final result being divided by ·915, so as to correct for the difference in the reducing powers of the sugars.

The reducing powers of some sugars compared with dextrose as unity are

Dextrose	1·000
Levulose	·915
Xylose	·983
Arabinose	1.032
Invert Sugar	·957
Galactose	·898
Lactose	·678
Maltose	·620

The Effect of Cane Sugar in the Determination of Reducing Sugars.—Cane sugar has a slight reducing action on the copper solution, and this action is proportional to the amount of cane sugar present, and to the amount of copper left unreduced; the error becomes very noticeable when bodies such as raw cane sugars containing 96 per cent. cane sugar and less than 1 per cent. reducing sugars are being analysed. This error is thus corrected by Browne.[8]

" The grms. of sucrose in the 25 c.c. of solution to be analysed by Allihn's method are divided by the mgrms. of dextrose found+40; the quotient will give the required correction in grms. to be deducted."

For the determination of invert sugar in the presence of cane sugar the methods of the Association of Official Agricultural Chemists, which are based on those of Herzfeld and of Meissl and Hiller, enjoin the use of a copper solution different from that of Allihn; for the determination of dextrose alone Allihn's copper solution is used; as the use of two solutions is inconvenient, the writer only gives the method of Browne for the correction due to the presence of cane sugar.

Necessity to adhere to the same Conditions.—The amount of copper reduced by a weight of reducing sugar depends on the time of boiling, the composition of the copper solution, the quantity used, and on the concentration of the sugar solution ; and hence where accuracy is desired the *exact* conditions under which the tables were constructed must be followed.

General Considerations of Gravimetric Processes.— The amount of copper reduced forms the basis of the calculation of the corresponding amount of reducing sugars ; provided only cuprous oxide were precipitated, weighings as cuprous oxide, as cupric oxide, as metallic copper, or determination of the copper by other methods would give equivalent results. In actual practice, and especially when dealing with low grade products, equivalence is not found. Zerban and Naquin[9], with pure invert sugar, invariably found that the weight of cuprous oxide was greater than should correspond with the weight of cupric oxide found after complete oxidation of the former. They found, in addition, that the weight of cupric oxide corresponded very closely with that of the copper determined in the precipitate, and this difference they attribute to the retention of water by the cuprous oxide. With actual factory products they found that the weight of both the cuprous and cupric oxide was greater than that which corresponded to the copper in the precipitate, and they attribute this to the co-precipitation of mineral matter weighed along with the precipitate. It follows, then, that the excess copper methods, to be considered accurate, demand the determination of the copper in the precipitate, which can be done electrolytically, by the permanganate or by the iodometric processes already given. In the writer's opinion, this last process combines both convenience and accuracy.

Direct Volumetric Methods.—In these methods a fixed quantity of alkaline copper tartrate solution is titrated with the solution under analysis until all the copper is reduced. The copper solution is usually known as Fehling's solution, and is of composition

Copper sulphate, 34·64 grms. per 1000 c.c.

Caustic soda, 80 grms., and potassium sodium tartrate, 180 grms. per 1000 c.c.

Equal quantities of the above are mixed, and 20 c.c. of the mixed solution are reduced by approximately ·05 grm. glucose.

As this method is the one usually employed in tropical sugar factories by unskilled workers, it is described in full detail, the remarks and directions applying *mutatis mutandis* to the other volumetric processes given. The mixed solution of copper sulphate and alkaline tartrate is known as Fehling's solution ; this is a deep blue solution which on boiling with glucose throws down a precipitate of red oxide of copper (cuprous oxide), the solution at the same time becoming lighter and eventually colourless, provided that a pure

solution of glucose be used. With cane juices, &c., the solution after precipitation of all the copper is yellow in colour. Fehling's solution, as sold in the shops, is twice as concentrated as the solution obtained by mixing equal bulks of the copper sulphate and the alkaline tartrate solutions, and 10 c.c. of the one or 20 c.c. of the other will be completely precipitated by approximately ·05 grm. of glucose. As Fehling's solution when mixed is apt to decompose, it should be standardized before use, and even if its components are kept separately it should still be standardized, as copper sulphate crystals are difficult to obtain pure. The standardization is performed by titrating the Fehling's solution with a solution of invert sugar of known composition until all the copper is precipitated; in subsequent analyses the conditions of the standardization must be strictly adhered to. The manipulation of a determination, whether standardization or analysis, is as follows:—

10 c.c. of Fehling's solution as found in the druggists' shops or 20 c.c. prepared as described above are placed in a small flask or large test tube and about 50 c.c. of water added; the exact quantity is immaterial so long as a fixed measure is adhered to. The whole is brought to the boil and the glucose solution added in quantities of 1 c.c. from a burette to the boiling Fehling's solution until the addition of 1 c.c. causes the final discharge of the blue colour. This preliminary experiment gives the amount of glucose solution required to the nearest c.c. If the number of c.c. taken differs materially from that of the solution used when standardizing, it should be diluted until of approximately the same strength. A second portion of Fehling's solution is now diluted and boiled and a quantity of glucose solution added, just a little less than that which the preliminary experiment has shown necessary, and the whole boiled for exactly two minutes; the glucose solution is then added drop by drop to the still boiling mixture until all the copper is reduced. Owing to the yellow colour of cane juices, &c., in alkaline solution, the disappearance of the blue colour is not sharp, and the critical point of the operation is determined as follows:—A solution of copper and potassium ferrocyanide in acetic acid solution gives an intense brown colouration. A drop of the nearly completely reduced Fehling's solution is removed in a *Wiley* or *Knorr* filtering tube and placed on a porcelain tile; to this is added a drop of potassium ferrocyanide solution and a drop of acetic acid: the presence of copper in solution is shown by a red colouration. This test is made for every drop of glucose solution added, after the blue colour has become indistinct.

Wiley's filter tube consists of a glass tube with a flange formed by softening one end and pressing on a wooden block; over this flange is tied a piece of linen and an asbestos film is formed on this by suction. Knorr modified this by sealing in the end of a glass tube a perforated platinum disc. On placing one of the tubes in the turbid liquid and applying suction, a little of the liquid is filtered through the asbestos free of copper oxide; after using each time the tube should be washed out.

The following method of filtration, is not inferior to the above : a number of filters are folded from papers about 3 cm. in diameter; one of these is grasped with the point of a small forceps and held in the material to be tested ; a clear solution passes into the interior of the filter from which one drop is removed with a pipette such as is used for filling fountain pens.

Ling and Rendle[10] use an indicator prepared as follows :—

One grm. each of ferrous ammonium sulphate and ammonium sulpho-cyanide are dissolved in 20 c.c. of water, to which is added 5 c.c. of hydrochloric acid; if necessary this is decolourized with a little zinc dust and the solution preserved out of contact with air ; a cupric salt gives an intense red colouration with this indicator ; the indicator becomes coloured after standing, but may be decolourized several times by the addition of zinc dust, its delicacy eventually becoming impaired.
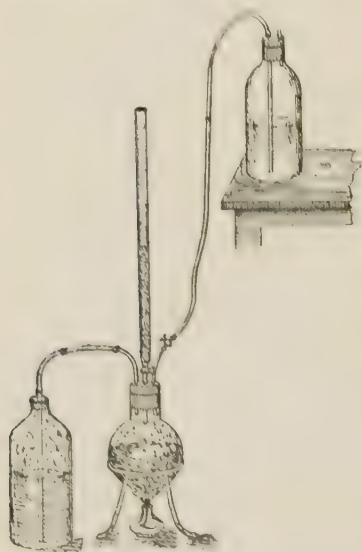
Fig. 258.

Pavy's Method.[11]—In Pavy's modification of Fehling's method, ammonia is added with the object of keeping in solution the cuprous oxide. The solution is prepared by adding to 120 c.c. of Fehling's solution (10 c.c. = ·05 grm. glucose) 300 c.c. of ammonia ·880, and making up to 1 litre ; 50 c.c. of this solution are reduced by ·025 grm. of glucose. The determination is made as follows :—The apparatus (*Fig. 258*), consists of a flask holding about 150 c.c , into the neck of which is fitted a rubber stopper carrying three tubes, one of which communicates with a reservoir of ammonia by a rubber tube carrying a screw clamp ; a second communicates with a burette containing the glucose solution, the flow of which is controlled with a screw clamp ; the third serves to carry away and condense under water the escaping fumes of ammonia. The whole apparatus is supported by suitable holders ; 50 c.c. of Pavy's solution are placed in the flask and boiled, ammonia being allowed to drip slowly into the flask. As soon as the air is expelled, indicated by the almost complete absorption of the escaping bubbles, the glucose solution is slowly added and continued until the blue colour is discharged ; the last few drops should be allowed to flow very slowly. The addition of the ammonia must be continued throughout the experiment, and as, notwithstanding the partial expulsion of the air on boiling, the reduced copper reoxidizes, the experiment should be made as expeditiously as is compatible with accuracy. The above remarks in describing Fehling's method as regards standardization, conditions of experiment, &c., are equally applicable here.

Peska's Method.[12]—Peska's modification of Pavy's method consists in covering the copper solution with a layer of pure paraffin and conducting the experiment at a temperature of 80° C., the copper solution not being allowed to boil. The solution employed by him is 6·9 grms. pure copper sulphate and 160 c.c. of 25 per cent. ammonia in 500 c.c. mixed immediately before use with an equal volume of 34·5 grms. Rochelle salt and 10 grms. of caustic soda, also in 500 c.c. ; 100 c.c. of the mixed reagent are reduced by 80·2 mgrms. of dextrose in 1 per cent. solution, or by 84·0 mgrms. of invert sugar in 1 per cent. solution.

Soldaini's Method.[13]—This process is not generally used in estimating reducing sugars, but is useful for the detection of small quantities of reducing sugars, and of cane sugar after inversion. A formula for its preparation is— copper sulphate, 3·464 grms. ; potassium bicarbonate, 297 grms. ; dissolve in 1000 c.c. ; equal volumes of this reagent and of the solution under inspection are boiled ; in the presence of reducing sugars the cuprous oxide separates in an intensely red condition ; as little as ·005 grm. sugar per 100 c.c. may be detected.

General Considerations of Volumetric Methods.—In the volumetric assay of glucose the Fehling solution is standardized against a solution of dextrose, invert or other sugar of known composition; the amount of copper reduced is, however, influenced by the time of boiling, by the concentration of the sugars, and by the simultaneous presence of cane sugar. The first two factors are capable of control, but the latter is not; the last factor is of greatest influence when the cane sugar is in great excess, as happens in the analysis of sugars ; the volumetric process then cannot lay claim to great accuracy unless the Fehling solution be standardized by a preliminary assay with cane sugar and reducing sugars in that proportion approximately in which they occur in the materials under analysis.

Ling and Rendle,[14] however, consider that the volumetric method, when properly conducted, gives results equally accurate with the gravimetric method, and at a considerable saving of time.

Preparation of Sugar Solutions for Reducing Sugar Assay.—The material used for the assay of reducing sugar may be submitted to the action of a clarifying agent or not, and very great differences in methods of working obtain. Pellet has repeatedly protested against the use of basic lead acetate, and it has been shown by Geerligs[15] and himself that this material, in the presence of chlorides, sulphates and other bodies carries down both dextrose and levulose ; on the other hand, with the use of no clarifying agent, bodies other than reducing sugars which act on the copper solution may be present ; for this reason it is customary with many chemists to use neutral acetate of lead as a clarifying agent. Zerban and Naquin[9] have shown that with cane molasses a little more copper is precipitated with unclarified solutions

than with solutions clarified with neutral acetate of lead, and the writer is of the opinion that results closest to the truth are obtained with the use of this material. In case clarification with a lead salt is used, the excess of lead must be removed; this may be done by the addition of a soluble sulphate, carbonate or oxalate.

The International Commission for Uniform Methods of Sugar Analysis, sitting in London in 1909, failed to agree on this point; basic lead acetate was forbidden, and neutral lead acetate was objected to by the English chemists only, so that no agreement was reached.

With no treatment at all the gravimetric process is impracticable with low grade products, owing to filtration being impossible; clarification with alumina cream will almost invariably overcome this difficulty.

Determination of Cane Sugar as Glucose.—On treatment with acids cane sugar is quantitatively converted into equal parts of dextrose and levulose, the mixture of the two being known as invert sugar; from 100 parts of cane sugar there are obtained 105·32 parts of invert sugar.

In most text books the scheme given is to determine the invert sugar in the sample before inversion. Let the invert sugar be in a sugar, say, 2·0 per cent. The sugar is then inverted and is now found to contain, say, 103·6 per cent. sugar, calculated as invert sugar; deducting the invert sugar there remains 101·6 per cent. cane sugar as invert sugar, and this converted to cane sugar by dividing by 1·0532, or by multiplying by ·95, gives the invert sugar as 96·52 per cent.

If this scheme is to be used as an accurate one it is essential that gravimetric processes be used to estimate the glucose, that the effect of the presence of cane sugar in determining the glucose originally present be allowed for, and that the correct factors connecting weight of copper be obtained. An example of the method of calculation is appended.

Ten grms. raw sugar were dissolved in 100 c.c., and 25 c.c. (= ·4 grm. sugar) treated according to Allihn's process; there were obtained 84·6 mgrms. copper = 43·2 mgrms. dextrose, equivalent to 45·1 mgrms. as invert sugar; hence the material contains approximately 1·13 per cent. reducing sugars as invert sugar. 10 c.c. of the above solution were inverted, neutralized, and made up to 200 c.c. 25 c.c. (= ·125 grms. sugar) treated according to Allihn's process gave 237·4 mgrms. copper = 122·5 mgrms. dextrose = 127·7 mgrms. invert sugar, or 102·32 per cent. total sugar as invert sugar. Deducting the invert sugar already found as present before inversion, there is due to the cane sugar 101·09 per cent. as invert sugar, which, converted to cane sugar, gives 96·04 per cent. as the approximate amount of cane sugar. Applying Browne's correction, i.e., dividing the grms. sucrose in the 25 c.c. of solution to be analysed by Allihn's method by the mgrms. of dextrose found + 40, the calculation appears: Approximate amount of cane sugar in 25 c.c.

of original solution ·96 × ·4 = ·384 ; mgrms. dextrose + 40 = 83·2 ; ·384 ÷ 83·2 = ·0046 grm. ; *i.e.*, 4·6 mgrms. dextrose are to be deducted from the amount found, which now appears as 43·2 — 4·6 = 38·6 mgrms. dextrose = 40·3 mgrms. invert sugar, or 1·07 per cent. as the correct amount of reducing sugars calculated as invert sugars.

The invert sugar due to the cane sugar is then 102·32 — 1·07 = 101·25 per cent. = 96·18 per cent. as the true amount of cane sugar present.

Optical Assay of Levulose.[16]—The rotation of levulose falls rapidly with rise of temperature; hence by observations of the optical activity at different temperatures the amount of levulose can be estimated; for each 1° C. rise in temperature and for 1 grm. levulose in 100 c.c , the rotation falls ·0357 Ventzke degree ; assuming the other sugars present are not affected, the amount of levulose present follows directly.

Identification of Levulose.—Pierarts[17] uses the following solution : per 1000 c.c. 12 grms. of glycocoll, 6 grms. freshly prepared cupric hydroxide, 50 grms. potassium carbonate ; in the cold this solution is reduced by levulose alone and by no other sugars which occur in analysis.

Direct Assay of Dextrose in the Presence of other Reducing Sugars.—Romijn's[18] method is based on the observation that dextrose and other aldose sugars readily oxidize iodine, levulose and ketose sugars having a very small oxidizing action at low temperatures. The assay is made as under. The iodine solution contains 40 grms. of borax and about 10 grms. of iodine per 1000 c.c. ; of this solution 25 c.c. are mixed with 25 c.c. of the solution under analysis which should contain about ·15 grms. sugar ; the mixed solutions are contained in a narrow necked flask with a long glass stopper ; the flask and its contents are then placed in a thermostat for 16—22 hours ; the stopper is wired down and the gutter between the stopper and neck of the flask is sealed with water. On removal from the thermostat the contents of the flasks are acidified with hydrochloric acid and the excess of iodine determined with thiosulphate. For 2 atoms of iodine 1 molecule of glucose is calculated. The reaction involved is given on page 462.

Separation of Dextrose and Levulose from Sucrose.[19]—Ammoniacal lead acetate prepared by adding ammonia to lead acetate until the opalescence which forms just disappears precipitates dextrose and levulose from solution ; the sucrose remains in solution as a soluble lead compound ; the precipitated lead-sugar compounds are suspended in water through which is passed a current of carbon dioxide ; the lead dextrose compound is decomposed and is removed by filtration ; the lead levulose compound may then be decomposed by hydrogen sulphide ; this method was used by Winter in pioneer work on the nature of the sugars of the cane, but is unsuited for ordinary laboratory routine.

CANE SUGAR.

REFERENCES IN CHAPTER XXIII.

1. *Zeit. für Rüb. Ind.*, 1889, 734.
2. *Le Rhum p.* 238.
3. *Handbook for Beet Sugar Chemists, p.*
4. *Zeit. für Anal. Chem.*, *12,* 296.
5. *Bull. Assoc.*, July, 1886 ; Sept., 1888.
6. After Sutton's *Volumetric Analysis, p.* 189.
7. *J. A. C. S.*, *24,* 1082.
8. *J. A. C. S.*, *28,* 4.
9. *I. S. J.*, 115.
10. *Analyst, 30,* 182.
11. *Chem. News, 39,* 77.
12. *Chem. News, 71,* 235.
13. *Zeit. für Rub. Ind.*, 1889, 933.
14. *Analyst, 33,* 160,
15. *I. S. J.*, 117.
16. Wiley, *Agric. Anal.*, Vol. III., 267.
17. *Bull. Assoc.*, *25,,* 830.
18. *Zeit. Anal. Chem.*, *36,* 349.
19. Wiley, *Agric. Anal.*, III., 283.

CHAPTER XXIV.

THE ASSAY OF SUGAR HOUSE PRODUCTS.

Determination of Water and Total Solids.—1. *By Specific Gravity.*—The connection between specific gravity and percentage of sugar in solution has been very accurately worked out, and hence if the specific gravity of a pure sugar solution be known the percentage of sugar is obtained by reference to tables; in actual sugar house work it is customary to treat all bodies present in solution as having the same effect on the density as has cane sugar; thus a juice of density 1·06566 is of the same density as a 16 per cent. solution of sugar, and this juice is conventionally returned as containing 16 per cent. *apparent total solids.* This determination is usually made by taking the density with a Brix hydrometer; this instrument is graduated on a sugar basis; that is to say, 16° Brix is indicated when the hydrometer is immersed in a 16 per cent. solution of sugar. The hydrometer consists of a glass instrument of the shape shown in *Fig. 259*; on the hydrometer being immersed in a liquid it will sink to a certain point, dependent on the density of the liquid; the point where the level of the liquid cuts the stem of the hydrometer gives on the scale the density of the liquid.

Owing to capillary attraction the liquid will rise as much as one-eighth of an inch up the stem of the hydrometer, *Fig. 260*; it is at the lower level that the reading is to be taken.

Westphal Balance.—The Westphal balance may also be used to obtain the specific gravity and apparent total solids of a sugar solution, as also may the pycnometer; these methods find no extended use in a sugar laboratory. As the determination of total solids from density is itself only approximate, there is no benefit obtained by a determination of the specific gravity to an extra decimal, and a determination by the hydrometer is in nearly every case of sufficient delicacy.

Standards of Reference.—The table connecting sucrose per cent. (Brix°) and density usually found are referred to water at 17·5° C. as unity; the hydrometers in use are graduated either at 17·5° C. or else for use in the tropics at 27·5° C.; let a Brix spindle correct at 17·5° C. indicate 20° at 28° C.; then from the table of corrections in the

Fig. 259.

Fig. 260.

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Appendix the true Brix is 20·72° and the specific gravity at 17·5° compared with water at 17·5° C. is 1·08652 as obtained by interpolation from the Brix table given in the Appendix; at the same time the specific gravity at 28° C. compared with water at 17·5° C. is that corresponding to 20° Brix or 1·08329; if the spindle is graduated at 27·5° C. and at this temperature reads 20°, the true Brix is 20 and the specific gravity at 17·5° C. compared with water at the same temperature is 1·08329; from the table of corrections a spindle graduated at 17·5° C. in place of reading 20° Brix would read (20 − ·68) = 19·33° B. and the specific gravity at 27·5° C. compared with water at 17·5° C. is then 1·08026. Nearly all chemists are agreed that readings should be taken at (or referred to) 20° C. and compared with water at 4° C. as standard. In the Appendix a Brix table on this basis is also given; whilst grudging the space occupied by the necessity of giving two tables, the present confusion of systems makes it obligatory. Any Beaumé table is purposely omitted as this irrational scale can disappear none too soon.
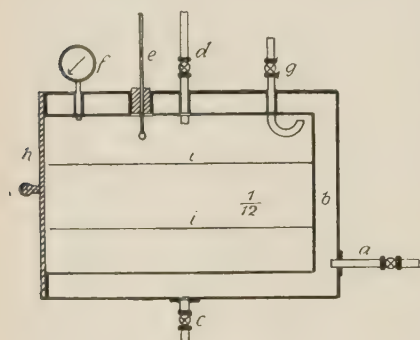
Fig. 261.

2. *By Drying to Constant Weight.* This method described below gives the true total solids and true water, and should be used in all analyses except when a rapid 'test,' as in the control of crystallization in motion processes, is required.

Sugar solutions on partial drying form a viscous mass from which the last parts of water are very slowly expelled under atmospheric pressure, and at the temperature of boiling water. As elevation of the temperature leads to decomposition of the organic matter, sugar solutions should be dried in vacuo, and at the same time as large a surface as possible should be exposed; this latter end is obtained by pouring the sugar solution over some such material as clean dry sand, pumice stone, or filter paper crimped into a wad. The routine of an analysis is as follows:—Into a flat dish of suitable size is placed a sufficient quantity of the absorbent material and the dish and its contents dried to constant weight; from 5 c.c. to 10 c.c. of the material under analysis is then run into the dish, which is then weighed a second time; the dish is then dried to constant weight.

In actual sugar house work it will be found very convenient to prepare in advance a large number of dishes containing sand, the sand being adjusted so that all the dishes are of uniform weight, and these are kept ready for use in a specially constructed dessicator of large size; as recommended by Spencer the lead capsules used as coverings for bottles are very convenient and cheap. The vacuum oven, used by the writer, which is capable of construction with plantation labour, is shown in *Fig. 261.* It consists of a piece of six-inch copper

piping about nine inches long; round this is constructed a steam chamber, b, into which exhaust steam from any convenient source is led through the pipe a; a pipe, c, carries away the condensed water; the interior of the oven is connected to the last vessel of the evaporator by a half inch pipe, d. One end of the oven is permanently closed, the other end being kept closed when in use by a metal disc, h, on which is fitted a washer of soft material. The external pressure of the atmosphere secures a tight joint, and thumb screws are quite unnecessary; in an oven of this diameter two shelves can be fitted, leaving room for the insertion of trays not more than half an inch high. The pipe g serves to break the vacuum and it may, if desired, be connected to a vacuum filtering apparatus. A thermometer and vacuum gauge are shown at e and f.
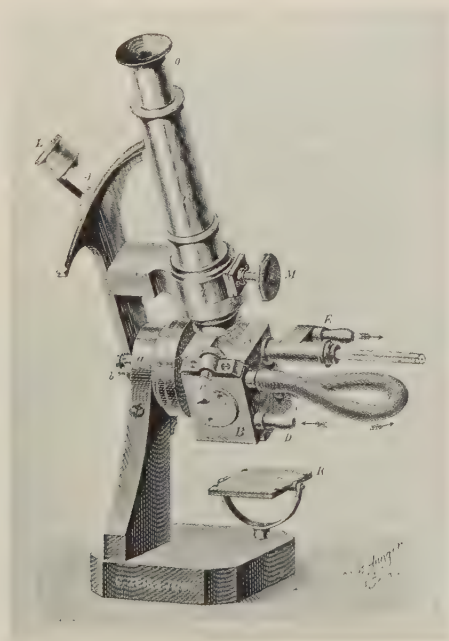
Fig. 262.

This type of oven may be obtained from dealers in apparatus, and is essentially similar to that originally described by Carr[1]; the use of sand is due to Wiley and Broadbent[2], and filter paper as an absorbent material was suggested by Josse[3].

3. *From the Refractive Index.*—It was shown originally by Main, whose results were completely confirmed by Geerligs[4], that the refractive index of sugar house products is in direct proportion to the true total solids, and that this relation obtains for all products from juice to waste molasses. The instrument most convenient for this purpose is the Abbé refractometer, *Fig. 262*, with

heatable prisms, as made by the firm of Zeiss, of Jena. The determination of the refractive index is made as follows:—The instrument is brought into a horizontal position, and the two prisms A and B separated by opening the milled head clamp at p; a drop of the material under analysis is placed on one of the prisms, which are then closed and secured by the clamp so as to obtain a film of material; the mirror R is then adjusted so as to throw a beam of light through the prisms; looking through the observation telescope at O and moving the alidade S on the left of the instrument, a dark shadow is seen to move over the field. The reference point is the coincidence of the edge of the shadow with the intersection of cross lines in the field of vision; the reading on the quadrant scale J gives directly the refractive index of the material under examination, whence can be obtained the percentage of dry matter from reference to the tables, given in the Appendix.

To maintain a constant temperature a stream of water should be allowed to pass through the coil $D\ E$, arranged in the instrument.

The milled head M on the right of the base of the observation telescope serves to correct for colour; when not adjusted, instead of a uniform dark shadow a coloured shadow appears, the dark shadow being obtained by rotation of the milled head.

In the Appendix is given a table connecting refractive index and per cent. of solids as arranged by Peck from Geerligs' data.

Determination of Ash.—The determination of the ash of sugar products offers no difficulties; the incineration is best performed in a platinum dish at a low red heat to prevent any volatilization of potash; as the sugary materials swell greatly on heating, the dish used must be capacious and the heating gradual.

It has been the custom with sugar analysts to determine the ash after a preliminary carbonization with sulphuric acid, and to correct for the increase in weight by deducting 10 per cent. from the recorded weight. This process is of course inaccurate, and, so far as regards the sugar materials the writer has encountered, unnecessary; the preliminary carbonization is claimed to render the materials more readily combustible.

Determination of Cane Sugar.—1. *In the Absence of Reducing Sugars.*—Weigh out a definite weight of material in a suitable vessel, such as the German silver vessels sold by dealers for this purpose; transfer to a flask graduated at 50 c.c. or 100 c.c., and clarify by one of the methods given in Chapter XXII.; make up to the mark, filter and take the polariscope reading; then if the material be dissolved in 100 c.c, and if the 20 cm. tube be used the percentage of sugar is given by the expression $\dfrac{R \times N}{W}$ where R is the observed reading, N is the normal weight of the polariscope used, and W is the weight of the material used.

If the liquid is already in the liquid form, the above procedure may be followed, or 100 c.c. of the material may be taken, and after clarification by one or other of the methods given, made up to 110 c.c., filtered and the polariscope reading of the filtrate taken ; then the percentage of sugar is given by the expression $\dfrac{1\cdot1\times R\times N}{100\times D}$ where D is the specific gravity of the material.

2. *In the Presence of Reducing Sugars.*—The sugar is obtained by the Clerget process described in Chapter XXII.

The following are irregularities in the method of analysis which are discussed under separate captions, and for which correction should be made :—

1. Volume of precipitate formed on clarification.
2. Temperature of observation.
3. Concentration of solution.
4. Change in the specific rotation of the sugars before and after inversion.

The estimation of cane sugar as glucose is given in Chapter XXIII.

Determination of Fibre.[*]—In routine analysis fibre means that part of the cane insoluble in water, and corresponds to the ' marc ' of the beet industry ; the fibre is determined by removing the soluble constituents by digestion with water or alcohol, and drying the residue to constant weight.

Pellet[5] has shown that extractions with alcohol in a Soxhlet apparatus give too high results, due to the precipitation by alcohol of bodies soluble in water, and also that all bodies soluble in cold water should be first removed to prevent a precipitation of albumenoids by hot water.

Analysis of the Cane.—The determination of the sugar in the cane may be made by an inferential approximate method, or by more complete methods.

Inferential Method.— Pass the cane under analysis through a hand mill, collect and polarize the expressed juice ; then the per cent. of sugar in the cane is given by the expression $(100-f)\,S$, where f is the per cent. of fibre in the cane, and S is the per cent. of sugar in the expressed juice. This method is open to the following sources of error :—The juice of the cane is not uniform, the first expressed juice being sweeter than that obtained later. The fibre, too, is a very variable quantity, and unless the fibre be actually determined a large error may be introduced. In Java it was once customary to estimate the sugar percentage of the cane as ·85 that of the sugar percentage of the first mill juice, but this factor is very dependent on variety.

Complete Methods.—1. Pass strips of the cane through a hand mill ; collect the expressed juice and crushed strips and weigh the latter at once ; take as the weight of juice expressed the difference between the weight of cane used and the weight of crushed strips or megass ; determine the sugar

percentage of the expressed juice, and thus the weight of sugar in the juice; determine separately the sugar percentage of the megass as given below, and thence the weight of sugar in the megass. The sum of these determinations is the weight of sugar in the weight of cane used.

2. *After Spencer*[6].—Spencer very properly remarks that it is impossible to satisfactorily comminute the cane without a special apparatus; he recommends for use the 'Hyatt' cane reducer *Fig. 263*; this consists of a series of circular staggered saws revolving at a high rate against which the cane is forced, the comminuted cane falling into a covered box; after obtaining the finely divided sample 100 grms. are placed in a suitable vessel and boiled for ten minutes with 100 c.c. of water; as much of the extract as possible is drained off and the operation repeated seven times, the woody residue being

Y. H W
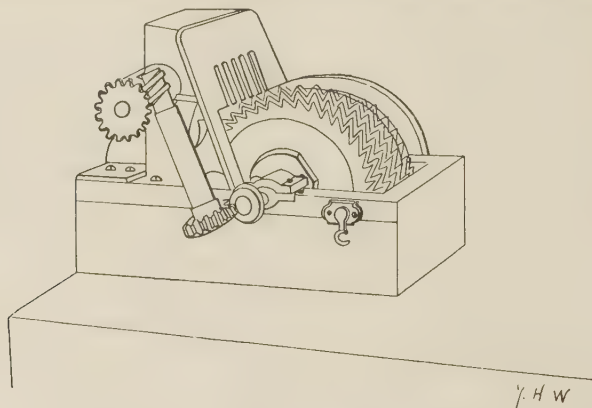
Fig. 263.

finally pressed in a hydraulic or other powerful press; after all the extracts are united and made up to definite volume, the united extract is analysed.

3. A fine sample of the cane is obtained as above and the sugar extracted in a Soxhlet apparatus, the extract made up to definite volume and its percentage of sugar determined; this is the process preferred by the writer.

4. *Zammaron's Method.*[7]—One hundred grms. of finely divided material are placed in a wire basket, and the basket and its contents placed in a copper vessel, at the bottom of which is a cock; 200 c.c. of water are placed in the vessel and boiled for ten to fifteen minutes; the extract is then drawn off by the cock and received in a litre flask; this process is repeated seven times, when about 960 c.c. of extract will have been obtained; basic lead acetate is then added to the extract in the litre flask, and its contents completed to 1000 c.c., and polarized after filtration.

In the writer's experience with finely divided cane there is no necessity for a prolonged boiling; of appliances for dividing the cane the Hyatt cane reducer and a 'jerked beef slicer' give very fine samples; the 'sausage chopper' often used does not give so fine a division.

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Glucose is determined in the extract obtained as above.

Ash is obtained by incinerating at a low red heat a portion of the finely divided cane.

Water is determined by drying to constant weight, preferably in vacuo.

Fibre is determined by repeatedly exhausting with water the megass obtained in sugar method *1*, or the finely divided cane, and drying the exhausted residue to constant weight.

When analysing cane or canes, it is of essential importance to remember that the cane is not of uniform composition, and a sample must represent the whole length of the cane. When making systematic control analyses of cane, the writer has pursued the following method :—A factory was grinding sixteen car-loads per hour ; from every car-load one cane was selected ; when sixteen canes were thus obtained, the top sixteenth was cut from the first, the second sixteenth from the second, and so on ; each piece of cane was then split longitudinally with a sharp knife, first into halves, then one half into quarters, and finally into eighths ; from the sixteen canes a sample weighing on an average 200—300 grms. was obtained representing each portion of the cane. Proceeding systematically on these lines, as many as 100 canes can easily be analysed in a day of eight hours.

Analysis of Megass.—*Water.*—The determination of water in megass so as to obtain figures representative of the working of the mills is a problem which is not so easily solved as at first sight appears. The chief difficulty lies in obtaining a sample of a bulk convenient for analysis and at the same time representative of the many tons of megass made in a day. In the writer's experience the very smallest sample for the actual analysis that can be obtained is one of about 50 grms. weight, obtained as a sub-sample from one of several kilograms taken across the whole width of the rollers. Megass is a material which is exceptionally retentive of moisture, and when dried under atmospheric pressure at the temperature of boiling water is completely dried only after heating for long periods. The time taken for drying depends very largely on the way the material is arranged in the oven ; the drying is quicker the greater the surface exposed. The writer has found shallow tin trays about 4–5 inches square and half an inch deep very suitable. Such trays easily hold 50 grms. of megass, exposing a large area ; gauze baskets or linen bags do not give such good results as regards time occupied in drying. When the drying is carried out at atmospheric pressure, a temperature in the oven of 240° F. is necessary if the megass is to be dried within a reasonable time ; megass placed in a layer in a shallow tray will be completely dried in from four to six hours at this temperature. Wherever possible, however, the vacuum oven already described should be used. Spencer[6] recommends that the samples taken for determination of moisture should be about 500 grms., and that it be contained in bags made of mosquito netting.

Sugar.—The process given in " Sugar and the Sugar Cane," and which is essentially the same as that given by Geerligs,[8] prescribed a diffusion in boiling water for fifteen minutes, about 50 grms. of megass and 250 c.c. of water being used. Following on the experiments of Pellet[9], this process is not sufficient to extract all the sugar, and he recommends the use of Zammaron's process.

Geerligs[10] has confirmed Pellet's observations on the analysis of megass in so far that he found a higher polarization of the extract on repeated boilings ; extraction in a Soxhlet apparatus with alcohol was, however, found to give results agreeable with a fifteen minutes' boiling. The higher results found on a longer boiling he attributes to a gradual solution of hemicelluloses, and comes to the conclusion that the fifteen minutes' boiling gives accurate results.

Norris[12] was unable to find any evidence of the solution of hemicelluloses on prolonged boiling, and with finely divided megass recommends a digestion of one hour as sufficient to extract all the sugar. In case a single extraction is made, the results are calculated as under—

	Grms.
Weight of megass	50
Weight basin, fibre and extract	459
Weight basin	212
Weight of extract and fibre	247

Allowing the megass to contain 45 per cent. fibre, the weight of the fibre is 22·5 grms. ; then the weight of the extract is 224·5 grms. Then if the extract polarizes 3·0 the percentage of sugar in the megass is

$$\frac{30 \times 26 \times 247 \times 100}{50}$$

the density of the extract being taken as unity without sensible error.

Davoll[11] suggests with good reason the necessity of making two determinations of water in megass : one on the fresh sample and one on that after preparation for sugar assay, results being calculated back to original moisture.

Glucose is determined in the extract obtained as above.

Fibre is obtained as described for fibre in cane.

It is customary in many sugar houses to determine the fibre in megass as under. An analysis gave the following results :—water, 48·50 per cent. ; sugar, 4·82 per cent. ; purity of last mill juice, 78·62 ; then solids in solution in megass $= \dfrac{4·82 \times 100}{78·62} = 6·13$ and fibre in megass $= 100 - 48·50 - 6·13 =$ 45·37 per cent. A possible error is introduced here by the acceptance of the purity of the last mill juice as being the same as that of the residual juice in the megass ; to determine this quantity the writer proceeds as follows :— about 20 grms. of megass are completely extracted in a Soxhlet apparatus, the extract evaporated to a volume of 50 c.c. and the total solids in the extract

determined by the refractometer; the percentage of fibre is then the quantity 100 — per cent. water — per cent. total solids. This calculation and method is of course applicable to cane also.

Analysis of the Juice.—The general methods for determination of density, degree Brix, total solids, have been already given in this Chapter; the actual routine of the determinations is here described.

Degree Brix.—The actual practice of taking the degree Brix or total solids is as follows:—If juice from the mill bed is being analysed, the sample is poured into a cylinder about twelve inches high by three inches diameter; this cylinder is provided at the bottom with a tubulure, in which is fitted a

perforated cork carrying a bent piece of glass tubing, which may be closed by a piece of india-rubber tubing and a clip; such cylinders with draw-off cocks ground in may be obtained at a small price from dealers in apparatus. The sample is allowed to stand for about five minutes, when the air bubbles will have risen to the surface and the dirt have sunk to the bottom; a clear negotiable sample can then be drawn off into a second cylinder, the hydrometer inserted, allowed to come to rest and the degree Brix noted; the temperature is taken at the moment of observation; for each degree Fahrenheit above or below that at which the hydrometer is graduated ·035
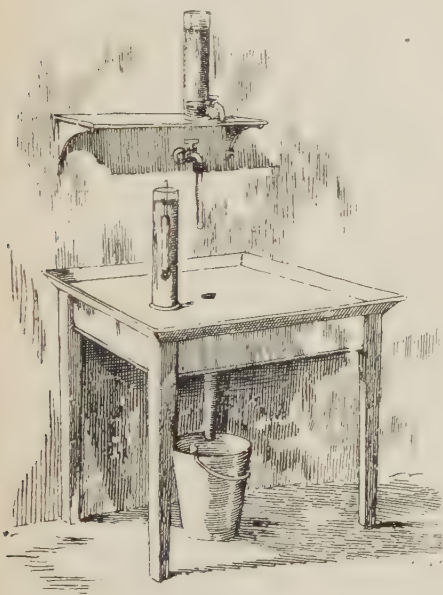
Fig. 263.

of a degree Brix should be added or subtracted. The preservation of samples for analysis is referred to in Chapter XXIV.

The apparatus for taking the density of the juices may conveniently be arranged as shown in *Fig. 263*; it is a shallow tray two feet square, lined with lead, from which leads a pipe to carry off waste; a tap for a water supply is arranged over the tray, by means of which a current of water is always available for cleaning apparatus and for cooling hot juices. Over the tray is placed a shelf in which are pierced a number of holes by means of which apparatus may be hung downwards to drain; the shelf also serves as a stand for cylinders in which the juice is settled. By the use of an arrangement like

this, the density determinations and sampling can be done without spilling juice about the laboratory, and the whole apparatus easily kept sweet and clean.

Purity.—The purity of a sugar product is the percentage of sugar on total solids; when the total solids are estimated from the density or degree Brix, the term *apparent* purity is used as distinguished from true purity when the total solids are determined by drying.

Sugar.—The determination of the sugar in the juice is carried out in actual practice as follows:—A flask with two graduation marks, one at 100 c.c. and the other at 110 c.c., is filled to the 100 c.c. mark with the sample of juice under analysis; 6 or 7 c.c. of a solution of basic lead acetate of density 1·25 are then added and the whole made up to 110 c.c. by the addition of water. The flask and contents are then violently shaken and filtered through a dry filter into a narrow cylinder; those sold by dealers as hydrometer immersion tubes, about six inches in height and one inch in diameter, serve admirably; the funnel which holds the filter paper may conveniently be stemless and rest on the rim of the receiving glass so as to prevent evaporation. After sufficient of the juice has been filtered, a 20 cm. polariscope tube is filled with the filtrate which must be perfectly clear and bright, the polariscope tube closed, placed in the trough of the polariscope and the reading observed. If N be the normal weight for the polariscope and R be the reading, the sugar in the juice as grms. per 100 c.c. is $\dfrac{N \times R \times 1 \cdot 1}{100}$; the pounds per gallon, as it is general to express results in many English factories, are one-tenth of this result; the percentage of sugar is obtained by dividing the grms. per 100 c.c. by the specific gravity. This routine can, of course, be varied; the normal weight of cane juice may be weighed out, a sufficiency of lead acetate added, the whole made up to 100 c.c., filtered and polarized; the reading in the polariscope will now give directly the percentage of sugar in the juice. Spencer's pipette is a convenient instrument for obtaining the normal weight of a cane juice without the use of the balance; the upper stem of an ordinary pipette is graduated with numbers corresponding to tenths of a degree Brix; when the pipette is filled to one of these marks the weight of liquid delivered is a multiple of the normal weight for juice of that particular degree Brix; for polariscopes which have a normal weight of 26·048 grms. these pipettes deliver twice, and for those whose normal weight is 16·19 grms. three times, the normal weight of juice. The polariscope reading (after making up to 100 c.c.) divided by two or three, as the case may be, gives the percentage of sugar in the juice.

Determination of Nitrogenous Bodies.—The determination of the nitrogenous bodies in cane juice is chiefly of interest to the agricultural side of a sugar estate; it forms, however, a means of testing the

efficiency of any new methods of clarification. Perhaps the most convenient process is Gunning's modification of the original Kjeldahl moist combustion process. In this process the material under analysis is heated with a mixture of sulphuric acid and potassium sulphate, until the solution has become colourless or of a pale straw colour. As applied to cane juice the process may be thus conducted : 20 c.c. of juice are evaporated to small bulk and washed into a 300 c.c. hard glass flask with 20 c.c. of concentrated sulphuric acid ; add, in small quantities at a time, 10 grms. powdered potassium sulphate ; heat very gently over a small flame till frothing stops, and then raise the temperature and allow to boil till the contents of the flask are colourless ; transfer to a hard glass litre flask, add caustic soda to distinct alkalinity and distil until all the ammonia is given off, collecting the distillate in 50 c.c. of decinormal acid ; determine the excess of acid remaining by titration with decinormal alkali ; bumping nearly always occurs near the end of the distillation, and to prevent this, the latter operation may be carried out by a current of steam, the flask itself being gently heated by a small flame. The caustic soda should be introduced through a stoppered thistle funnel and the distillation flask provided with a safety bulb to prevent any of the contents of the flask being carried over mechanically. The sulphuric acid used should be tested by means of a blank experiment for nitrogen and the quantity found deducted from subsequent determinations.

Determination of Amides[13].

—The material is boiled for one hour with a 5 per cent. solution of sulphuric or hydrochloric acid, at the end of which time the amide nitrogen is converted into ammonium salts ; after exact neutralization with sodium carbonate the material is distilled over magnesia free of carbonates, and the distillate is collected in standard acid and the ammonia evolved determined in the usual way. Half the nitrogen of the amide bodies is thus obtained as ammonia ; it is customary to calculate the ammonia thus obtained to asparagin $C_4H_8N_2O_3$; if ammonia salts are present these are determined separately.

Determination of Albumenoid Nitrogen[13].

—Place ·7 grm. of the substance in a beaker, add 100 c.c. of water, and heat to boiling ; add a quantity of Stutzer's reagent containing about ·5 grm. copper hydroxide, filter when cold, wash with cold water, and determine the nitrogen in the precipitate.

Stutzer's reagent is thus prepared : dissolve 100 grms. copper sulphate in 5 litres of water, add 2·5 c.c. glycerol, and then a dilute solution of sodium hydroxide until the solution is just alkaline ; filter, rub the precipitate up with water containing 5 c.c. of glycerol per litre, and wash by decantation on filtration until the washings are no longer alkaline. Rub the precipitate up again in a mortar with water containing 10 per cent. of glycerol, thus preparing

a uniform gelatinous mass that can be measured with a pipette. Determine the amount of copper hydroxide per c.c. of this mixture.

Determination of Gums.—By gums are meant those bodies insoluble in alcohol ; 100 c.c. of juice are concentrated to a volume of about 20 c.c., and poured into 100 c.c. of 90 per cent. alcohol containing 1 c.c. hydrochloric acid. The precipitate is allowed to settle and washed by decantation with strong alcohol, collected on a tared filter paper or better in a Gooch crucible, and dried to constant weight. The increase in weight gives gums and ash ; the weight of ash is determined, and being deducted from the weight of gum and ash gives the weight of gum.

Acidity and Alkalinity.—1. 100 c.c. of the juice are titrated from a burette with decinormal alkali ; to the juice a few drops of phenolphthalein solution are added, the neutralization of the excess of acid being shown by the appearance of a pink colouration. The juice may be conveniently contained in a white porcelain basin. In this method the juice is alkaline to litmus before the appearance of the pink colour.

2. To 50 c.c. of the juice an excess of alkali is added and the volume completed to 100 c.c. To successive further quantities of 50 c.c. varying quantities of decinormal alkali are added and the volume completed to 100 c.c. The minimum quantity of alkali that gives a juice of the same tint as that to which an excess of alkali was added is a measure of the acidity of the juice. The tint may be observed in small test tubes of about half-an-inch diameter.

The point of exact neutrality in cane juice is hard to determine, the change not being sharp, but a dirty olive-green colour obtaining over as many as 4 to 5 c.c. of decinormal alkali ; and when indicators are used the change is masked by the colour of the juice.

Carbonated Juices.—The carbonation process, which is but sparingly used in cane sugar factories, requires special methods for its control ; an abstract of the methods employed in beet sugar factories may be given here.

It is customary to determine the alkalinity of the juice of the first and second saturation in terms of lime as CaO ; as this determination has to be done rapidly, special methods of moderate accuracy are employed. One of the simplest and most convenient is Vivien's. A standard acid containing ·875 grm. H_2SO_4 per 1000 c.c. is prepared ; the acid is standardized against decinormal alkali ; 10 c.c. of the latter are equivalent to 56 c.c. of the acid which, when exactly made up, neutralizes volume for volume a solution containing ·05 grm. lime per 1000 c.c. ; the indicator employed is phenolphthalein, which is placed in the stock of standard acid. The tube, *Fig. 264*, is filled to the zero mark, and the standard acid added ; as long as lime is

in excess the juice remains red, becoming finally colourless when the lime is neutralized. Each ten divisions in the tube correspond to ·1 grm. lime per 1000 c.c. For juice of the second saturation a weaker acid only one-fifth the strength of the above is used.

The determination of the total lime in the juice is performed by the usual methods; 100 c.c. juice are heated to boiling, ammonia added in excess and filtered if necessary; the lime is precipitated by ammonium oxalate from the hot solution, boiled for two hours, filtered, washed, dried, and weighed as carbonate or sulphate.

The alkalinity of a juice is in part due to caustic soda and potash set free by the action of lime on the salts of the former present in the juice; when it is wished to determine the alkalinity due to lime and to soda and potash, Pellet's method may be used. 1. Determine the total alkalinity by titration with sulphuric acid, using litmus as an indicator and making the titration at the boiling point. 2. To a volume of the juice add an equal bulk of alcohol which will precipitate the lime as an insoluble saccharate; filter, and in an integral part of the filtrate determine the alkalinity; the latter is due to free caustic potash and soda but is expressed as lime for purposes of convenience; by determining the total lime, the combined lime can be likewise obtained.

Analysis of Massecuites and Molasses.—The

Fig. 264.

sugar, glucose, ash, alkalinity, gums, moisture, &c., are determined by the general methods already given.

Density.—The density of a massecuite has a two-fold meaning: firstly, the apparent density of the material as it actually exists, a figure required to calculate the weight of the factory product from its cubage, and secondly the true density required in the control of the boiling.

The method used by the writer is as below :—
A large wide-mouthed vessel of the slope shown in *Fig. 265* is constructed of copper or brass, or even a wide-mouthed bottle may be employed, if the mouth of the vessel is formed sloping inwards and a stopper is ground accurately to fit this mouth; through the centre of the stopper is bored a hole about $\frac{1}{8}$ in. in diameter. Massecuite from the pan is allowed to flow into the vessel until about seven-eighths full; the vessel is then allowed to cool until it has reached the temperature at which the factory measurements of massecuite are taken, and the weight of massecuite determined. Water is then carefully poured over the surface of the massecuite till the vessel is full, the stopper inserted, when the excess of water escapes through the aperture and is wiped off. The method of calculation is shown below :—

Fig. 265

	Grms.
Weight of vessel and stopper empty	416·35
,, ,, ,, and water..	2163·40
,, water	1747·05
,, vessel, stopper, and massecuite	2645·95
,, massecuite	2229·60
,, vessel, stopper, massecuite, and water ..	2875·95
,, water above massecuite	230
,, water in space occupied by massecuite ..	1517·05

Apparent specific gravity of massecuite .. .. .. $\dfrac{2229\cdot60}{1517\cdot05}$ $= 1\cdot469$

In using this method no attempt is made to remove imprisoned air-bubbles, the object of the determination being to facsimilize the actual working of the factory.

An accurate determination of actual specific gravity of a massecuite can be made by this method, using instead of water an indifferent material such as oil. This is introduced into a wide-mouthed vessel similar to the one already described; an oil of already determined density is poured over it, and the two mixed until air-bubbles are no longer seen to rise. The stirrer may conveniently be a piece of iron rod, of such a length that it may remain in the vessel without interfering with the insertion of the stopper. After removal of the air-bubbles the vessel is filled up with oil and the determination completed as above. An example follows: —

	Grms.
Weight of vessel, stopper and stirrer	453·75
,, ,, ,, ,, and oil	1838·35
Specific gravity of oil (water 1·0)..	·8550
Weight of oil	1384·95
,, vessel, stopper, stirrer and massecuite ..	2548·35
,, massecuite	2095·65
,, vessel, &c., massecuite and oil	2743·20
,, oil above massecuite..	194·85
,, oil in space occupied by massecuite ..	1190·10

Real specific gravity of massecuite $\dfrac{2095\cdot65}{1190\cdot10} \times \cdot855 =$ 1·5056

In technical control the density of a massecuite or molasses is often determined by dilution and taking the degree Brix of the diluted material. An example will make the method clear; 250 grms. of a massecuite dissolved in water and made up to 1000 c.c. stand at 20·8° Brix; the total solids present in the 1000 c.c. and also in the 250 grms. of material used are then ·208 × 1077·4 = 224·1 ; whence the percentage of solids or degree Brix of the masse-cuite is 89·64, corresponding to a density of 1·491. The water per cent. in the massecuite is, of course, the difference between 100 and the total solids— in this case, 10·36 per cent.

Crystallized and Dissolved Sugar.—The total sugar in a massecuite or molasses exists in two forms, either separated out as crystals, or still remaining in solution in the necessarily accompanying water; in general two similar juices, similarly treated and boiled to the same water content, will separate out the same amount of crystals, but the actual recovery at the centrifugals may be widely different. For in one case, by skilful pan-boiling, the crystallized sugar is obtained in a form permitting of easy separation from the molasses, and in a second, the presence of fine crystals may cause considerable losses. The determination of the crystallized sugar affords a valuable check on the pan-boiler.

FIG. 266.

Vivien's Method[14].—Weigh out about 200 grms. of massecuite and place in the funnel of the pressure filtering apparatus, as in *Fig. 266*, connect the apparatus to a filter pump, and wash with a cold saturated solution of pure sugar and water until all molasses are removed; transfer the crystals to a tared dish and obtain their weight. Remove about 10 grms. and dry to constant weight to determine the water adhering to the crystals. At a temperature of 84°F., for each one part of water 2·125 parts of sugar are dissolved in a saturated solution. This last determination gives data to calculate the weight of washing syrup which has replaced the molasses; an example is appended.

Weight of massecuite, 200 grms.; weight of washed crystals, 175 grms.; percentage of water in washed crystals, 6·54. Then total moisture in washed crystals $= \dfrac{175 \times 6\cdot54}{100} = 12\cdot62$, and wash liquor in washed crystals $= 12\cdot62 \times 3\cdot125^* = 35\cdot77$ grms., and weight of crystals $175 - 35\cdot77 = 139\cdot23$ grms., or 69·66 per cent. on weight of massecuite.

Dupont's Method[14].—Heat the massecuite to a temperature of 80°C. and centrifugal in a small hand machine, the wire basket of which is covered with thin flannel or some similar material; polarize the molasses and the cured sugar and calculate the percentage of crystallized sugar from the following formula: $x = \dfrac{a - p^{\prime}}{p - p^{\prime\prime}}$, where $x =$ weight of crystallized sugar in one part of massecuite, a the percentage of sugar in the massecuite, p the percentage of sugar in the cured crystals, and $p^{\prime}$ that in the molasses.

This formula is applicable for use on the factory scale, provided no water is used in curing, and that the molasses are filtered through flannel before analysis so as to remove fine crystals; if water be used in small quantities and if the amount can be calculated, the sugar percentage of the molasses can be corrected for dilution, but in this case the formula will not give results so correct.

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* For a temperature of 84° F.

Geerligs' Method.[15]—This method depends on the observation that sugar crystals themselves only contain a trace of ash, the ash of commercial sugars being due to the accompanying molasses; hence, in a massecuite the ash is due solely to the molasses. Determine the percentage of ash in the massecuite and in its molasses freed from fine grain by filtration through glasswool; as an example, let the massecuite contain 2·25 per cent. and the molasses 6·07 per cent. ash; then the percentage of molasses in the massecuite is $\frac{2\cdot25}{6\cdot07} \times 100 = 37\cdot07$ per cent.; the remainder 63·93 per cent. being crystallized sugar.

Method used by the Writer.—On the plate of a Buchner funnel, arranged as in *Fig. 256*, is placed a layer of glasswool, after which the funnel is filled with the massecuite under analysis. On connecting to the vacuum the molasses, entirely freed from crystals, passes through.

Let x and y be the proportions of sugar in the massecuite and filtered molasses, respectively, and let s be the proportion of sugar as crystals per unit of massecuite.

Then $x = (1-s)\,y + s$, whence $s = \dfrac{x-y}{1-y}$

This equation gives the amount of crystals of *pure* sugar; actually, in practice, the crystals are obtained with an adhering layer of molasses which increases the weight as indicated by this analysis.

These methods have been described as applicable to massecuites; they are, of course, applicable to molasses to determine the quantity of fine grain which has been separated on cooling or is present after having passed through the mesh of the centrifugal basket.

Rapid Scheme for Technical Control.—1. Weigh out from 150 to 200 grms. of material, dissolve in water, and make up to 1000 c.c.

2. Determine the density of this solution with the Brix hydrometer; then the degree Brix or apparent total solids of the massecuite is $\dfrac{B \times d \times 1000}{w}$ where B and d are the degree Brix and the density of the solution respectively, and w is the weight of the material taken.

3. Obtain the polariscope reading of the solution exactly as described for the juice. Then the apparent per cent. of sugar in the massecuite is $\dfrac{1000 \times p \times N}{w \times 100}$ where p is the polarization of the solution, N the normal weight of the polariscope, and w the weight of material taken.

4. The apparent purity is obtained by dividing the apparent sugar percentage by the apparent Brix.

In many cases in rapid technical control it is only the apparent purity that is required; it is then only necessary to make up a solution to any convenient density and determine the apparent purity of this solution exactly as described for juice.

Analysis of Filter - Press Cake.—*Water.*—Dry to constant weight at a temperature of 105°C. The use of a vacuum oven, though permissible, is not so necessary as in the case of juices and molasses, &c.

Sugar.—The amount of insoluble matter in filter-press cake is so considerable that error is introduced if the volume is not allowed for. Well-pressed cake contains on an average 40 per cent. of insoluble matter, which occupies about 20 c.c. per 100 grms.; the volume occupied by the insoluble matter in 25 grms. is then about 5 c.c., and if this quantity be weighed out and made up to 100 c.c. after addition of lead acetate, the polariscope reading will indicate at once the apparent percentage of sugar; or instead, the normal weight may be weighed out and polarized after making up to 105 c.c.

In factories using the carbonation process, saccharates of lime may occur in the press cake. Before polarization these must be decomposed; the decomposition can be effected by the passage of a current of carbon dioxide, or more conveniently by the addition of a few drops of acetic acid.

Analysis of Sugars.—*Polarization.*—The routine of a polariscope test of sugar is as follows:—

The normal weight of sugar is weighed out in a suitable vessel, transferred to a 100 c.c. flask, and dissolved in water; if necessary the sugar solution is clarified with lead acetate, then made up to 100 c.c., filtered, and the polariscope reading of the solution obtained; the result is the *polarization*, and on this test sugars are bought and sold. It cannot be too strongly insisted on that the *polarization* and the percentage of sugar as determined by the methods given already, in which the manifold sources of error are eliminated, are two entirely distinct terms.

In the determination of the polarization a minimum of lead acetate is to be used, and a correction for volume of lead precipitate is not applied.

The water, ash, &c., are determined by the methods already given.

The Detection and Estimation of small Quantities of Sugar.—*Molisch's Reaction,*[16] depending on the production of a red colouration by small quantities of sugar in the presence of sulphuric acid, is thus carried out. 5 c.c. of concentrated sulphuric acid are placed in a test tube, into which is then run 2 c.c. of the water supposed to contain sugar, followed by the addition of two or three drops of a 5 per cent. alcoholic solution of a-naphthol; the contents of the test tube are shaken, and the colour produced compared with that obtained with known quantities of sugar; as little as one part of sugar in 1,000,000 can be detected. If the sulphuric acid alone produces the reaction it should be boiled to destroy organic matter before use.

Pinoff's Ammonium Molybdate reaction was originally given as a test for 'glucose,' and is applied by Pinoff[17] to levulose: ·1 grm. of

material, 10 c.c. of a 4 per cent. solution ammonium molybdate, 10 c.c. water, and ·2 c.c. glacial acetic acid are heated at 95°C.; levulose in three minutes gives a fine blue colouration; all sugars give the same reaction in the presence of mineral acids. The writer modifies this test as follows:—To a suspected water 2 per cent. of hydrochloric acid of 1·18 sp. gr. is added, placed in a test tube, and heated on the water bath for five minutes; an equal quantity of a 5 per cent. solution of ammonium molybdate is then added, and the heating continued for five minutes; in the presence of sugars a blue colouration is produced, which may be compared with previously prepared samples. The colour thus produced may be simulated by solutions of copper sulphate prepared to represent the colouration produced by 1 part of sugar in 20,000, &c.

Analysis of Waste Waters.—Sugar is detected and estimated in waste waters by Molisch's or Pinoff's reactions given in a previous paragraph; if sugar is present in sufficient quantity, the waste waters may be concentrated and the sugar determined by the polariscope, or as glucose after inversion.

Analysis of Cattle Food or Molascuit. — Cattle food is a mixture of molasses and finely comminated megass, from 25 per cent. to 30 per cent. of the latter being used. It is usually sold on its percentage of sugars expressed as glucose. The method used by the writer is as follows:— About five grms. of material are introduced into a funnel and washed with successive quantities of water until all soluble matter is removed; the united washings are inverted, neutralized, made up to 1000 c.c., and the glucose determined by one or other of the methods already given. The fibre is determined by drying the insoluble residue to constant weight.

A Soxhlet extractor may also be used for the separation of the soluble matter from the fibre.

The Analysis of Limestone and Lime.—It is not general for sugar factories to prepare their own lime, but in the carbonation process it is necessary, and where a supply of limestone is abundant, as in Mauritius and Barbados, it is cheaper to burn lime than to import. The choice of limestone is important and it is advisable also to keep a check on the composition of the purchased lime.

Moisture.—Dry 1–2 grms. to constant weight.

Sand, Insoluble and Organic Matter.—Dissolve about 1 grm. in hydrochloric acid, filter through a tared filter paper, wash and dry at 100° C.; weigh, giving the weight of sand, &c., ignite and weigh obtaining the sand, the difference of the two weights giving the organic matter.

Soluble Silica. — Evaporate to complete dryness the filtrate from the determination of the sand, &c.; moisten the residue and again evaporate to dryness, keeping the residue at a temperature of 120° C. for an hour after the

residue is apparently dry; take up with hot water, filter and wash till free of chlorides; dry, ignite, and weigh the residue SiO_2.

Insoluble Silica.—Mix the residue obtained in the determination of the sand with four or five times its weight of fusion mixture, composed of molecular proportions of sodium and potassium carbonates, and keep at a red heat for half an hour after effervescence has ceased; dissolve out with dilute hydrochloric acid, evaporate to dryness and determine the silica as before.

Iron, Alumina.—Mix the filtrates from the determinations of soluble and insoluble silica; evaporate to convenient bulk, add ammonia till alkaline, and heat till the solution smells only faintly of ammonia; filter while hot; wash, dry, ignite, and weigh the precipitate as $Fe_2O_3 + Al_2O_3$. If there be present any large quantity of iron and alumina after decanting off the supernatant liquid, the precipitate should be dissolved in hydrochloric acid and re-precipitated.

Lime.—Precipitate the lime in the filtrate from the iron and alumina while boiling hot with ammonium oxalate; allow to stand for six hours, and filter, wash, dry and ignite the precipitate to constant weight and weigh as CaO; convert the lime to sulphate or carbonate by evaporation to dryness with either sulphate or carbonate of ammonia and again ignite, and weigh as $CaSO_4$, or as $CaCO_3$; $CaCO_3 \times \cdot 56 = CaO$; $CaSO_4 \times \cdot 4118 = CaO$.

Magnesia.—Precipitate the magnesia in the filtrate from the lime determination as phosphate by the addition of sodium phosphate; agitate the solution violently, and allow to stand for twelve hours; filter, wash with dilute ammonia, dry, ignite strongly, and weigh as $Mg_2P_2O_7$: $Mg_2P_2O_7 \times \cdot 3604 = MgO$.

As magnesia is detrimental to the value of good limestone, Geerligs has given a scheme for its rapid estimation. Two grms. are dissolved in hydrochloric acid, evaporated to complete dryness, the residue brought into solution with hydrochloric acid, boiled after the addition of a few drops of nitric acid, and evaporated to small bulk. An excess of calcium carbonate is added to precipitate iron and alumina, the precipitate filtered off, and the filtrate collected in a flask to which an excess of lime water is added; the flask is filled nearly to the neck and set aside to settle; the supernatant liquid is decanted through a filter, and the precipitate washed by decantation. The precipitate from the lime water contains the magnesia; it is dissolved in hydrochloric acid, the lime precipitated as before by ammonium oxalate, and the magnesia determined in the filtrate.

The method of Sundström for the rapid estimation of magnesia in limestones is as follows:—

Weigh out one grm. of material into a small dish, add about 100 c.c. water and 25 c.c. of normal hydrochloric acid; heat to boiling, allow to cool and titrate the excess of acid with normal caustic soda, thus obtaining the

quantity of acid required to neutralize the carbonates of lime and magnesia. The lime is determined as usual and calculated to carbonate; if the percentage of calcium carbonate be divided by five, the quotient will give the number of c.c. of normal hydrochloric acid required to neutralize the calcium carbonate; the difference between that found above as necessary to neutralize the lime and magnesia carbonates, and the calculated number of c.c. necessary for the lime alone, gives the number of c.c. requisite to neutralize the magnesia carbonate; this number, multiplied by 4 2, gives the percentage of magnesia carbonate.

Sulphuric Acid.—Dissolve about five grms. in dilute hydrochloric acid; separate the silica as before, and in the hot filtrate precipitate the sulphuric acid by barium chloride; allow to settle for six hours, filter, wash, dry, ignite, and weigh as $BaSO_4$; $BaSO_4 \times \cdot 3427 = SO_3$: $BaSO_4 \times \cdot 5828 = CaSO_4$.

The analysis of the lime is performed exactly as for limestone; very often large quantities of alkalies are found in the lime, especially if the limestone has been burnt with wood fuel in a short flame kiln. In addition to the chemical analysis of the lime, a mechanical bulk analysis for the determination of stones, unburnt limestone, &c., may be made; very considerable quantities of these materials are often found. The following are special methods of lime analysis :—

Free Lime.—Dissolve about one grm. of lime in a 25 to 30 per cent. solution of sugar; make up to definite volume, filter and titrate an aliquot part of the filtrate with normal acid.

Unburned and Slaked Lime.—Dissolve about one grm. of lime in a definite quantity of normal acid and determine the excess of acid by titration with normal alkali; the difference between the total lime as thus found and the free lime as found above gives the unburnt lime.

Degener-Lunge Method.—Slake about one grm. of lime with water and titrate with normal acid, using phenacetoline as indicator. The point at which the indicator changes from yellow to red marks the neutralization of the free lime; the addition of acid being continued, the point at which the unburnt and slaked lime are neutralized is marked by a change from red to golden yellow.

REFERENCES IN CHAPTER XXIV.

1. Wiley, *Agric. Anal.*, III., 22.
2. *Chem. News, 52,* 280.
3. *Bull. Assoc.,* 1893, 656.
4. *I. S. J.,* 110.
5. *I. S. J.,* 80.
6. *Handbook for Cane Sugar Manufacturers,* p. 113.
7. *Bull. Assoc.,* 1897, 74.
8. *I. S. J.,* 68.
9. *I. S. J.,* 79.
10. *Arch.,* 1908, 3.
11. *I. S. J.,* 120.
12. *Bull. 32. Agric. H. S. P. A.*
13. *U.S.D.A. Bur. of Chem. Bull.* 107.
14. Quoted in Spencer's *Handbook.*
15. *S. C.,* 309.
16. Wiley, *Agric. Anal.,* III., 195.
17. *Ber. Deut. Chem. Gesel. 38,* 3308.

CHAPTER XXV.

THE CONTROL OF THE FACTORY.

By the term ' chemical control' it is not meant that the control of the factory should be given over to any one but the manager, but there is implied a system of routine analysis and sampling combined with an organized scheme of technical book-keeping whereby the chemist can detect, locate, correct and hence *control* any imperfections of the process of manufacture.

To obtain this end three postulates are demanded, correct weights, correct samples and correct analyses; neglect of any one of these three will vitiate the control, but as shown in some sections below incorrect measurements may, in some cases, be indicated from analytical data alone and it is not the least of the duties of the chemist to check the weights against the analyses; this is particularly the case where the cane is bought or where its weight forms a basis of payment for the labour.

In addition the sugar factory should be regarded as a huge chemical experiment and efforts should be made to account for every pound of sugar entering the factory. The points necessary to the control as defined above are discussed below.

Direct Measurements.—*Canes.*—What is regarded as the weight of cane is not the same in all factories; in some the gross weight is used and in others an arbitrary allowance is made for trash, dirt, &c. ; there can be no doubt that, for control work, the weight of cane should be defined as that material which actually passes between the rollers of the mills.

The balances used to weigh canes are of the conventional type; they should be repeatedly checked and adjusted and the (in general) native clerk should be carefully watched especially when the weight of cane forms a basis of payment to contractors or when canes are purchased from native planters. Balances automatic in action and self-registering are to be bought, and these are beyond the control of the operator whose functions are merely mechanical.

Juices.—In most factories the determination of the weight of liquids is obtained from volume measurements and when carefully conducted and controlled accurate estimates are possible. The most convenient scheme is to employ two or more tanks for the reception of the cold juice, which also may serve as liming tanks; in each of these tanks a slot is cut on one side and the flow of juice is continued until it freely overflows ; a constant volume is thus ensured ; the overflow is received in a gutter and returns to the juice pump tank. The volume of juice combined with density and temperature

observations gives the data to calculate its weight. Tanks of symmetrical pattern can be readily gauged, and if there is reason to suspect their symmetry they must be calibrated by filling into them water from some convenient measure such as a 100 gallon cask.

In some factories conveniences for measuring the cold juice are absent and it is only possible to measure the hot juice; allowance must then be made for expansion and for evaporation. Taking the volume of a 15 per cent. sugar solution at 84°F. as unity, the volume at 180° F. is 1·0216, at 185° F. is 1·0285, at 190° F. is 1·0303, at 195°F. is 1·0327, at 200° F. is 1·0345, and at 205° F. is 1·0377; the expansion of the juice is so great compared with the expansion of the receiving tanks and so many other sources of error are introduced that change in volume of these may be neglected.

The weight of water evaporated in heating is given by the following formula:—Weight of water evaporated per unit of evaporated juice $= \dfrac{B_2 - B_1}{B_1}$ where B_1 and B_2 are the degrees Brix of the raw and heated juice respectively.
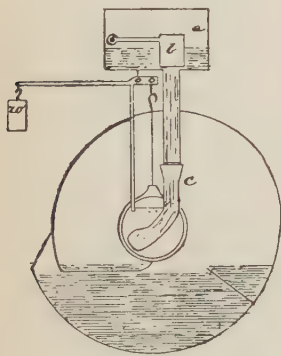
Howe Juice Scales.—In the Howe scales two tanks are arranged on a weigh bridge; when one tank has received so much juice as to approach a pre-arranged limit, the flow to that tank is cut off; balance is made by an attendant adjusting a sliding weight; pulling a lever stamps on a card the net weight contained; the tank then discharges its contents while the second one is filling.

Baldwin's Juice Weigher.—This appliance for automatically weighing the juice is illustrated in *Fig. 267*; the drum *c* is divided into compartments, of which one is filling while another is emptying; this drum is suspended from one end of a steel yard; juice flows into one compartment from the tank *a* and when balance between the drum and its contents and the counterpoise *w* is obtained, the flow of juice is automatically turned into the other compartment; as this compartment fills, the drum soon revolves and discharges the juice from the weighed compartment; when balance is nearly obtained, the flow of juice from *a* is moderated automatically; at each weighing a small sample of juice is diverted into a bottle.

Hedemann Weigher.—This appliance is constructed by the Honolulu Ironworks; it consists (*Fig. 268*) of a container *a a* divided into two compartments by a partition; this container is mounted on a knife edge; arranged along its

upper edge is a hollow pipe *b b*, partly filled with mercury; the juice, first of all, flows into the overhead receptacle *d* and thence discharges into one compartment of the container *a a*; when a certain amount of juice dependent on the quantity of mercury in *b b* has flowed in, the compartment tilts and dumps its load. The juice now flows into the other compartment, and when the same quantity has flowed in the same action again takes place. It is necessary to calibrate the amount of juice discharged at each
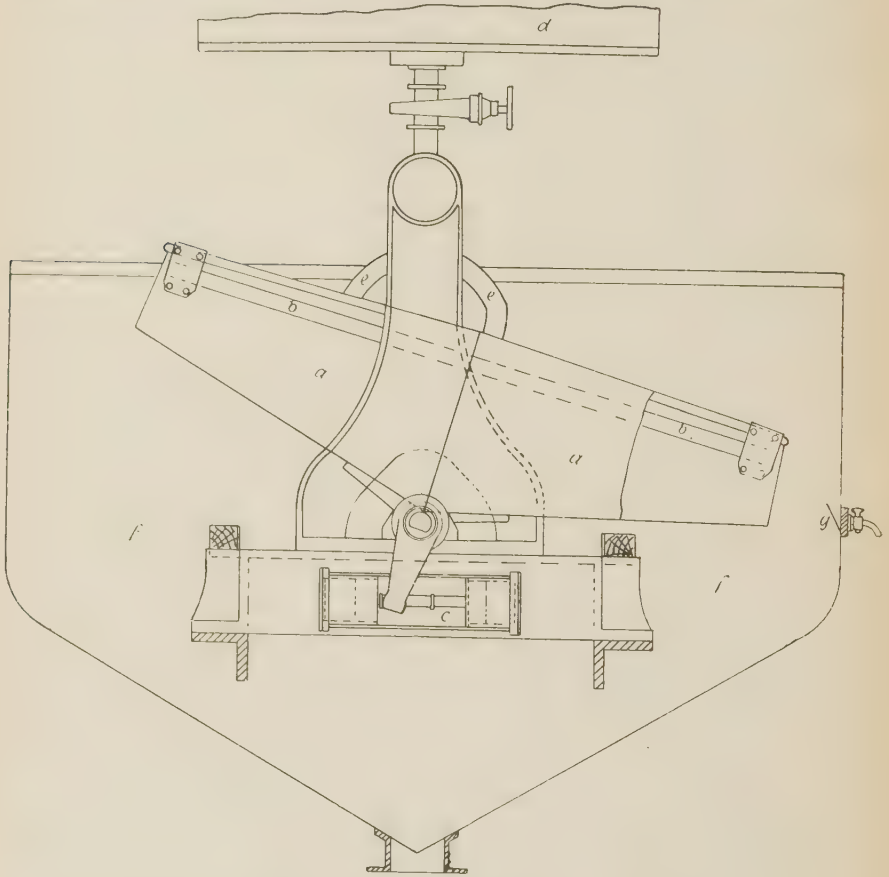
FIG. 268.

dump by actual experiment; a counter registers the number of dumps and a sample of juice is taken at each dump from the cock *g*; an arrangement of air-cushion cylinders at *c* serves as a dashpot to prevent shock.

Richardson Weigher.[1]—This apparatus is shown in *Fig. 269*; it consists of a strong iron frame, supporting the equal armed beam *A*; to one end of the beam is hung the weighing tank or hopper, *B*, in which the liquid is carried, and to the others is suspended the counter balance or weight box, *C*.

The quantity determined on is represented by the weights placed in the weight box, which furnish the power to actuate the scale. The supply of the liquid into the scale is from the upper hopper tank, D, which is fed by the feed, E, which forms its joint by descending on to the rubber seating, F. This valve is raised through the plunger, G, by the power of the weight in the box, C, and is controlled by means of the levers, K and L, which form a dead centre.
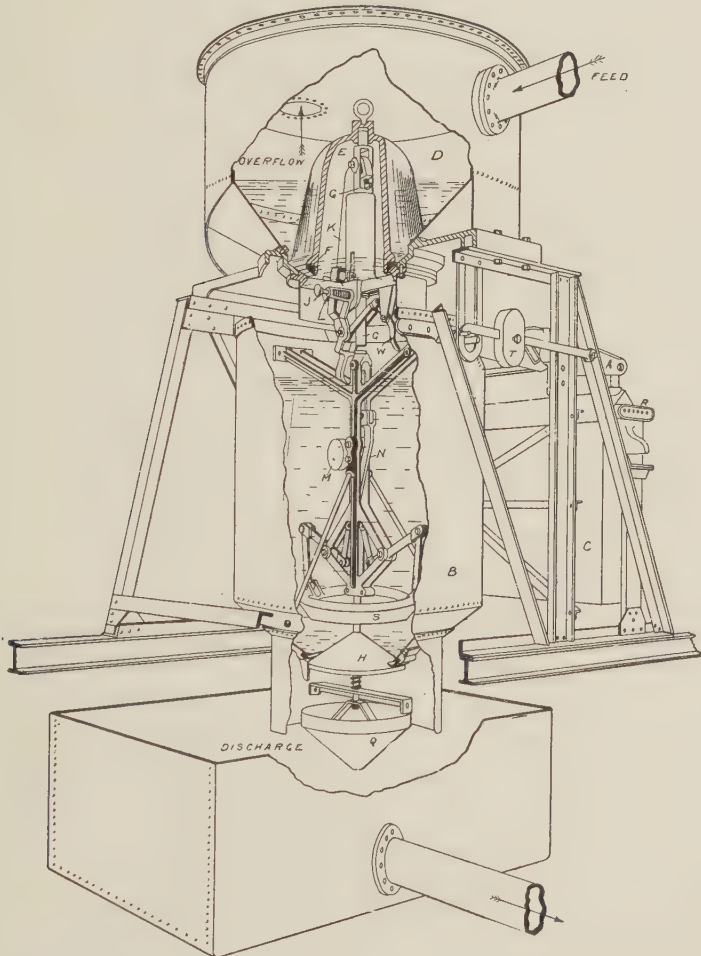
Fig. 269.

A full stream of liquid enters the weighing tank, B, until its weight in the hopper begins to off-set the counterpoise, and in so doing releases the plunger, G. The valve now partially closes and only a reduced flow enters the hopper until the balance is reached. This final flow may be enlarged or reduced, by means of the screw J. At the balance, the beam trips the arm,

W, and the valve completely closes. The lever, *L*, engages with the lever, *N*, breaking the lock formed by the dead centre of levers *N* and *M*, and the weight of the liquid opens the outlet valve and the contents of the tank are discharged. This discharge is controlled by the conical valve, *H*, which also has a rubber seating, and thus a joint is formed against the wall of the tank at *S*.

It will be seen that the liquid is delivered on to the tun-dish, *Q*, connected with the outlet valve, *H*, and the weight of the liquid on this tun-dish has the effect of holding the valve open until all the liquid is drained from the weighing tank. This valve returns by means of the weighted lever, *M*, when relieved of the weight of the liquid on the tun-dish, *Q*.

The sides of the tank are continued down to prevent splashing, and a mechanical counter, *R*, registers every weighing.

This apparatus has been installed at Puunene, at Oahu, and at Nipe Bay, which are among the largest factories in the world.
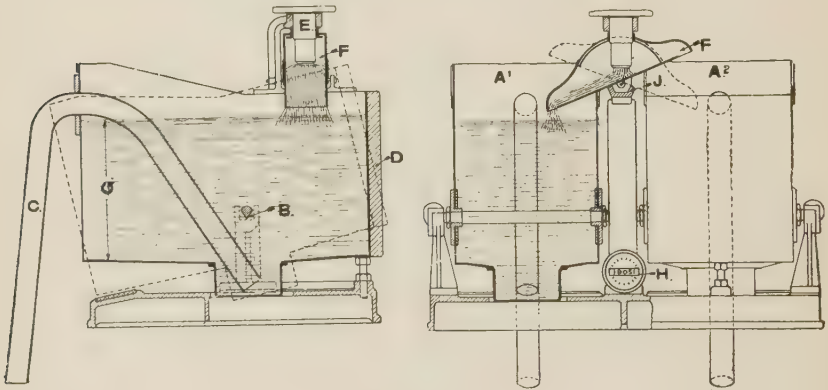
Fig. 270.

Leinert Meter.—This apparatus (*Fig. 270*) consists of two tanks of equal capacity A_1 and A_2; they are balanced on a knife edge *B*; at *C* is a syphon pipe and at *D* is arranged an adjustable counter-weight. The juice discharges from the pipe *E* into the gutter *F* which is tilted one way or the other by the movements of the tanks; the juice flows into one tank until the weight is just sufficient to counterpoise that at *D*, when the tank tilts into the position shown by the dotted lines and allows the juice to discharge through the syphon; simultaneously the gutter is tilted and directs the flow of juice to the other tank; the number of fillings is registered by an automatic counter.

Megass.—It is only exceptionally that the weight of the megass is directly determined, although this would afford a control of great value. In some Demerara factories, where water carriage presented great difficulties for

a direct weighing of cane, it was once customary to receive the megass in trucks passing over a weigh bridge; the economies to be obtained by the adoption of automatic firing led to the abandonment of this scheme. The best means of weighing the megass is afforded, the writer believes, by the use of a travelling band weigher, such as the Blake-Dennison. Actually in practice it is general to obtain the weight of the megass from the ratio of the fibre in cane and in megass.

Added Water.—Any of the appliances used for obtaining the weight of the juice are of course equally applicable to obtain the weight of the added water; actually, however, the only direct measurement the writer has ever seen used is by the employment of two tanks, one filling while the other empties. The weight of water added is usually deduced from the equation—

$$\text{Canes} + \text{water} = \text{mixed juice} + \text{megass},$$

the weight of megass being obtained from the ratio of the fibre in cane to fibre in megass.

In a subsequent section it is shown how the weight of added water can be calculated from analytical data and one direct measurement of any one of the above quantities.

It must be carefully borne in mind that the water usually calculated as present in the juice does not represent the whole amount added since a part of this goes away in the megass and that the dilution represents only the dilution on the amount of juice expressed.

Weight of Press Cake.—The press cake can be easily weighed in the trucks in which it is received for removal; if this is not possible a figure of reasonable accuracy can be obtained by determining the average weight of one press, and by keeping a tally of the number of presses filled.

Weight of Syrup.—The weight of syrup can be obtained from a record of the number of tanks filled combined with determinations of its density; to be of value this record must be made with the same care as is afforded the measurement of the juice.

Weight of Massecuites.—It is only in exceptional cases that the factory arrangements are such that the massecuites can be weighed, and in general their weight is deduced from volume measurements in combination with observations of their density.

Weight of Waste Molasses.—The weight of waste molasses is usually obtained from observations of the volume and density of the low massecuites combined with observations of the weight of sugar obtained on purging. In some Hawaiian factories it is the practice now to weigh all the waste molasses on beam scales before they are finally discharged.

Weight of Sugars.—This quantity is always carefully weighed, in some cases on automatic scales; these machines which automatically fill a fixed quantity of sugar into the bags, and also register the number of bags filled, only work to their best advantage with very dry sugars.

Density of Absolute Juice of the Cane.—As shown in the following section a knowledge of this quantity or of its relation to the density of the first expressed juice affords a basis for an oversight of the recorded weights and measurements. The writer has used the following scheme :— The sample of cane is crushed in a hand mill, and from the weight of megass obtained the weight of juice expressed results; the density or degree Brix of this juice is obtained. A sub-sample of the megass is taken, extracted in a Soxhlet apparatus, the extract concentrated to small bulk, say, 50 c.c., and the density of this extract obtained; the refractometer forms a most useful appliance in this determination. An example of the method follows :—

Weight of cane, 1000 grms.

Weight of juice, 670 grms.

Weight of megass, 330 grms.

Juice was of 20·0° Brix; the megass contained 50·0 per cent. water; the extract, from 20 grms. of megass concentrated to 50·0 c.c., contained 4·2 per cent. solids, and was of density 1·0165; the soluble solids in 20 grms. of megass are then $\dfrac{50 \times 1{\cdot}0165 \times 4{\cdot}2}{100} = 2{\cdot}135$ or 10·67 per cent.; the megass then contains 60·67 per cent. of juice, which contains 17·61 per cent. of soluble solids; the amount of juice in the megass is per 100 cane $33 \times {\cdot}6067 = 20{\cdot}02$; the Brix of the whole juice of the cane is then $\dfrac{67 \times 20 + 20{\cdot}02 \times 17{\cdot}61}{67 + 20{\cdot}02} = 19{\cdot}43$ and the ratio of Brix of whole juice to Brix of crusher juice is $\dfrac{19{\cdot}43}{20{\cdot}00} = {\cdot}9715$.

Inferential Control of Weights.—When the Cheribon cane formed the staple cane of Java it was found that the relation

$$\frac{\text{sucrose in cane}}{\text{sucrose in first mill juice}} = {\cdot}85$$

obtained very generally and this factor was used to obtain a preliminary estimate of the weight of cane and it was also used to control the weights, as if a different factor was found it was considered *prima facie* evidence of an error in weights or analyses.

With the substitution of other canes it was found that this factor was subject to variation and could no longer be used.

Nevertheless the writer thinks that the determination of this factor on large samples of cane in a hand mill might reasonably form a part of the daily routine, the figure so found being compared with that obtained from the factory results; any large difference would indicate an error which it should be the business of the executive to locate and to rectify.

Another inferential control of the weights is obtained by the use of the following equation—

$$\text{Canes} + \text{water} = \text{mixed juice} + \text{megass};$$

data for solution of this equation can be obtained from the ordinary routine analyses and one measurement as under.[2] Let f be the fibre in cane, m be the fibre in megass, B_c, B_j, B_m be the degrees Brix respectively of the absolute juice, mixed juice, and residual juice in the megass. Let the weight of canes be unity and the weight of the mixed juice be a; from well-known equations the weight of megass is $\dfrac{f}{m}$ and the weight of the juice in the megass is $\dfrac{f}{m}(1-m)$.

The total weight of juice is then $a + \dfrac{f}{m}(1-m)$. The solids in the total weight of juice then are

$$a\ B_j + \frac{f}{m}(1-m)\ B_m$$

and the total solids per unit of juice are

$$\frac{a\ B_j + \dfrac{f}{m}(1-m)\ B_m}{a + \dfrac{f}{m}(1-m)}$$

$$= \frac{a\ B_j m + f\ (1-m)\ B_m}{a\ m + f\ (1-m)}$$

The water added per unit of original juice in the cane is then

$$\frac{B_c - \dfrac{a\ B_j\ m + f\ (1-m)\ B_m}{a\ m + f\ (1-m)}}{\dfrac{a\ B_j m + f\ (1-m)\ B_m}{a\ m + f\ (1-m)}}$$

$$= \frac{a\ B_c\ m + f\ B_c - f\ m\ B_c - a\ B_j\ m - f\ B_m + f\ m\ B_m}{a\ B_j\ m + f\ B_m - f\ m\ B_m}$$

Let this expression be denoted by P. The weight of original juice is $1 - f$; hence the total weight of added water is $(1 - f)\ P$. Hence from the equation—

$$\text{Canes} + \text{water} = \text{mixed juice} + \text{megass}$$

$$1 + (1 - f)\ P = a + \frac{f}{m}.$$

A numerical example will show the application of this equation.

The following analytical data (expressed per unity) were found :—

B_c ·209 (*i.e.*, 20·9 Brix); f ·119; m ·487; B_j ·190; B_m ·088; hence $\dfrac{f}{m} = $ ·2443 and $1 - f = $ ·881.

From these quantities P is found to be

$$\frac{·0093a + ·0074}{·0925a + ·0054}$$

Whence

$$1 + ·881\left(\frac{·0093a + ·0074}{·0925a + ·0054}\right) = a + ·2443.$$

Solving this equation, a is found to be ·9125, *i.e.*, the weight of mixed juice is 91·25 per cent. of the weight of the cane, and if the actually observed records do not agree with this determination then an error is indicated as being present.

FIG. 271.

In the above argument B_c is the quantity representing the total solids in the whole juice in the cane; it is not usual to determine this quantity directly and in some factories it is even customary to take the Brix of the first expressed juice as representing this quantity.

The factor connecting the Brix of the first expressed juice and the Brix of the whole or absolute juice of the cane is capable of ready determination; the equation obtained above may also be used to obtain the relation between the Brix of the first expressed juice and the absolute juice, the actually recorded weights of cane and juice being employed; the factors found from analysis and from the recorded measurements should agree; a difference indicates an error.

With canes of 12 per cent. fibre and first expressed juice equal in weight of 60 per cent. of the cane, the writer has found that the following relation holds :—

$$\text{(Brix of first expressed juice)} \cdot 97 = \text{Brix of absolute juice.}$$

Automatic Record of Density.—

Langen's Apparatus for recording the density of the juice is shown in *Fig. 271*; the juice enters a containing vessel f and overflowing at d passes away at h; a constant level of juice is thus maintained; inside the narrow central portion of the vessel is a tube s, to the lower end of which is attached a rubber ball g; the upper portion of this tube is funnel-shaped; this inner tube is filled with water; the height of the water is dependent on the pressure on the rubber ball, the pressure being in turn dependent on the density of the juice. The level of the water is recorded by means of the float c, which carries a pencil a pressing against the cylinder b, which revolves by a clockwork arrangement every 24 hours;

FIG. 272.

the lower portion of the inner tube is formed into a spiral at e, so as to ensure the juice and water being of the same temperature.
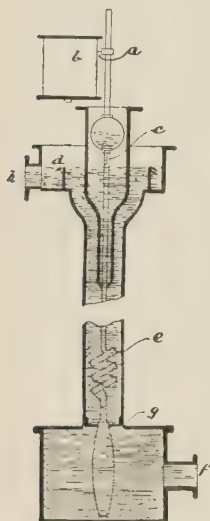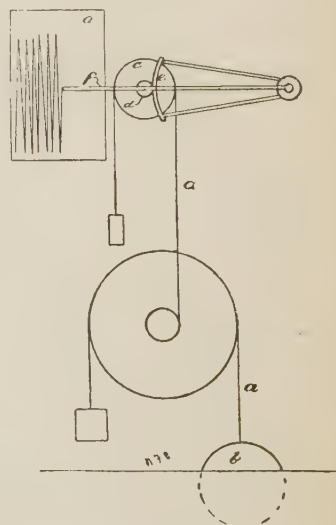
Horsin-Déon's Apparatus, shown diagrammatically in *Fig. 272*, is designed to record the height of the juice in the receiving tanks. A wire or chain $a\,a$ transmits motion from a float b in the tank to a drum c which revolves when the float rises or falls; a pinion d on this drum in turn drives a rack e which carries a pencil f pressing against a cylinder g which revolves once in every twelve hours; the height to which the pencil rises is governed by the height of the juice in the tank, and, conversely, the pencil will show if the measuring tanks have been properly emptied or whether through carelessness any 'running on bottoms' has occurred.

Dilution.—The dilution is calculated either as a percentage on the normal juice expressed or as a percentage on the mixed juice. If B_1 and B_2 are the degrees Brix of the normal and of the mixed juice, then water present in mixed juice per unit of normal juice is given by the expression $\dfrac{B_1 - B_2}{B_2}$ and per unit of mixed juice by the expression $\dfrac{B_1 - B_2}{B_1}$.

In this calculation it is not unusual to take B_1 as the degree Brix of the first mill juice; in other cases a factor is used to connect the Brix of the first mill juice with that obtained when the mills work without added water.

Extraction.—The extraction is the amount of sugar obtained in the juice per 100 sugar in canes; where direct measurements are used this figure is at once obtainable; in the majority of cases this is not the case and resource must be had to inferential methods which were first used by Icéry.[3] If f be the fibre in the cane, and m be the fibre in the megass, then the weight of megass per unit weight of cane is $\dfrac{f}{m}$ and the weight of juice per unit weight of cane is $1 - \dfrac{f}{m} = \dfrac{m - f}{m}$. Consequently if the fibre in the cane and in the megass are known, and also the weight of either the juice or the megass, the other data can be calculated; an example is appended.

Recorded Data.—Tons of cane 550; tons mixed juice 500; fibre in cane 11 per cent.; fibre in megass 44 per cent.; sucrose per cent. in mixed juice 13 per cent.; sucrose per cent. in megass 4·0 per cent. Then

$$\text{Tons megass} = \frac{11}{44} \times 550 = 137\cdot5$$

$$\text{Tons sucrose in megass} = 137\cdot5 \times \cdot04 = 5\cdot5$$
$$\text{Tons sucrose in juice} = 500 \times \cdot13 = 65\cdot0$$
$$\text{Tons sucrose in cane} = 65\cdot0 \times 5\cdot5 = 70\cdot5$$

$$\text{Extraction} = \frac{65\cdot0 \times 100}{70\cdot5} = 92\cdot19 \text{ per cent.}$$

$$\text{Sucrose per cent. in cane} = \frac{70\cdot5 \times 100}{550} = 12\cdot81 \text{ per cent.}$$

The extraction can also be obtained from analytical data only without any weighings, as under:

	Per cent.
Sucrose per cent. in cane (from analysis)	12·81
Sucrose per cent. in megass	4·0
Fibre per cent. in cane	11·0
Fibre per cent. in megass	44·0

$$\text{Then megass per 100 cane} = 100 \times \frac{11}{44} = 25\text{·}00$$

$$\text{Sucrose in megass per 100 cane} = \frac{25 \times 4}{100} = 1\text{·}00$$

$$\text{Sucrose in juice per 100 cane} = 12\text{·}81 - 1\text{·}00 = 11\text{·}81$$

$$\text{Extraction} = \frac{11\text{·}81 \times 100}{12\text{·}81} = 92\text{·}19 \text{ per cent.}$$

Then if the weight of cane is known the sugar entering the boiling house is readily calculated.

Sampling Juices.—Where the juices are received in tanks, no better scheme can be devised than to take a fixed quantity from each tank or if the tanks are of unequal size a quantity proportional to the volume of each; the samples are stored in a large bottle in which has been placed an antiseptic; the preservatives most used are corrosive sublimate, one part to 5000 or a 40 per cent. solution of formaldehyde (formalin) one part to 2000. Allowance is made for the corrosive sublimate in determining the density of the juice. These preservatives will keep the juices unchanged for twelve hours but nevertheless the containers used for sampling should be kept scrupulously clean.

Where the juice to be sampled is not measured, a continuous sampler must be arranged.

Fig. 273.

Such a one is shown in *Fig. 273*; *a* is the main juice pipe into which is fitted a short piece of iron or copper pipe, *b*, of half-inch internal diameter; a perforated cork carrying the bent piece of glass tubing *c* emerges from the end of the pipe *b* and is continued to the bottom of the bottle *d*; it is preferable to make this pipe in two portions connected by a piece of indiarubber tubing;

the glass tube e which delivers the juice to the receptacle f only extends to the middle of the bottle d; about one inch from the bottom of the bottle is fixed a piece of fine wire gauze; the end of the tube f is drawn out into a fine point. The object of the bottle d is to act as a dashpot, and that of the gauze to keep back fine particles which might choke the end of the tube e. By connecting the tube e to a tall cylinder with a tubulure at the bottom as shown at g, the cylinder can be kept full with a continual flow of juice, and a hydrometer placed therein will allow of the density of the juice being continually under observation. Where the last mill juice is pumped separately, this simple apparatus is invaluable in guiding the attendant at the water tanks.

A very simple and convenient sampler may be arranged by connecting a stout wire to the juice being sampled; if, for example, the first mill juice is being sampled, a large bottle, in the neck of which is a funnel, is placed close to the mill; a stout copper wire is then arranged so that one end rests on the funnel, and the other leans against the mill roller; the juice flows down the wire and drips into the funnel, the amount of sample collected being dependent on the size of the wire. In using this sampler it must be borne in mind that the composition of juice from the front and back rollers varies very much and especially so with maceration.

Sampling of Megass.—Well crushed megass coming away in a uniform blanket is easily sampled, the only precaution necessary being to take into account the megass at the ends of the rollers, which is frequently imperfectly crushed; it is hence best to take a large sample, going right across the breadth of the mill, to mix this thoroughly and then to take a sub-sample from the large sample. Megass when sampled must be weighed for analysis at once, as it rapidly loses or absorbs moisture. Geerligs[4] has shown that megass can be preserved for indefinite periods by means of intermittent sterilization in sealed vessels, but this process is, perhaps, too troublesome for use except in special cases.

Sampling of Syrup.—A definite quantity of syrup is taken by the attendant from each tank filled, and stored in a large bottle; the analysis is made on the accumulated samples; if the bottles used are well washed and kept strictly clean no preservative is necessary.

Sampling of Massecuites.—As each pan is struck, a sample of the masse-cuite should be allowed to fall into a suitable vessel, such as a large wide-mouthed bottle; one sample from each pan strike is not sufficient, as masse-cuite varies in composition in different parts of the pan, and a sample should be taken at the beginning, middle, and end of the strike. When the receptacle is full it should be sent to the laboratory for sub-sampling. Massecuites will keep for long periods, and a daily analysis is not necessary; an accurate analysis of a massecuite, particularly of a low one, is a process which takes

considerable time ; a fully accurate analysis of a carefully taken week's sample is of much more value than six inaccurate daily analyses.

Massecuites received in tanks for crystallization in motion are best sampled after they have been stirred for a short time.

Sampling of Press Cake.—A hollow cylinder with bevelled cutting edge may conveniently be used to bore out samples of press cake; it must be remembered that the sugar content of press cakes varies largely with position.

Sampling of Molasses.—Considerable variations in the composition of molasses as they leave the baskets may be observed, and it is better to take the sample from the tanks in which they are received. In case the molasses are run to waste directly, they should be systematically sampled at frequent intervals.

Sampling of Sugars.—This is generally done by instructing the foreman at the sugar filling station to throw a pinch of sugar from each bag filled into a receptacle ; the writer prefers to take the sample from a large number of bags from each consignment that leaves the factory. It must be specially remembered that sugars lose or gain in weight very rapidly, and care should be taken that the sample analysed, in so far as regards its percentage of moisture, corresponds with the main body of the sugars from which it was taken.

Control of the Milling Plant.—The most generally used figure, as a criterion of the power exerted by the mills, is the water percentage of the megass ; that this is not an accurate basis is shown by the following example :—

Let a megass be of composition : fibre 40 per cent., juice 60 per cent., the juice being of density 1·065 and containing 16·6 per cent. solids and 83·4 per cent. water. The water content of the megass is then 50 per cent. Now suppose for this juice an equal volume of juice is substituted of density 1·040 and containing 10·5 per cent. solids and 89·5 per cent. water ; the crushing is evidently equally good in both cases, but now in the second case the weight of the juice is reduced from 60 to 58·6 and the weight of water increased to 52·45, which calculated on the reduced weight of megass, 98·6 of the first weight, gives a water content of 53·2 per cent. ; at the same time the fibre content varies and for the example quoted is increased from 40 per cent. to 40·5 per cent., a much smaller variation, so that the fibre content of a megass forms a much more accurate basis of comparison. A true basis of comparison is given by the expression

$$\frac{\text{Weight of juice in unit weight of megass}}{\text{Weight of fibre in unit weight of megass} \times \text{density of juice}}$$

which expresses the volume of juice in megass per unit weight of fibre in the megass.

A control or oversight of the efficiency of the added water can be obtained by the use of the following methods[5] :—

1. *The Density of the Last Mill Juice.*— On the supposition that the density of the juice is constant throughout the cane (a supposition that is not very far from the truth) it is easy to obtain the density of the last mill juice when complete admixture is assumed. For example, let canes with 12 per cent. of fibre be crushed until they contain 45 per cent. of fibre; then the weight of juice remaining in the megass per unit weight of cane is $\dfrac{\cdot 12\ (1\ -\ \cdot 45)}{\cdot 45} = \cdot 1467$; let this juice be of density 18° Brix, and let water 20 per cent. on cane be added with complete admixture. Then the density after mixture, *i.e.*, the density of the last mill juice is $\dfrac{\cdot 1467 \times 18}{\cdot 1467 + \cdot 2} = 7 \cdot 61$.

In Table I., at the end of this section, is calculated for a single maceration process the density of the last mill juice for degrees Brix in the normal juice from 15 to 22, and for added water per 100 cane from 10 to 50, the dry crushed megass containing 45 per cent. of fibre, and the cane containing 12 per cent. of fibre. As the mixture becomes less complete, less solids are extracted, and the density of the last mill juice will fall. This table and calculation is introduced as a means of checking the efficiency of the added water.

2. *Comparison of Last Mill Juice with the Residual Juice in Megass.*— A number of years ago it was the custom in Java mills to work out a 'coefficient of admixture of added water' on the following lines:

$$\text{Sugar per cent. in residual juice in megass} = \frac{\text{Sugar per cent. in megass}}{1 - \text{fibre per cent. in megass}} \times 100.$$

$$\text{Coefficient of admixture} = \frac{\text{Sugar per cent. in last mill juice}}{\text{Sugar per cent. in residual juice}}.$$

This figure does not appear in the more recent reports, and for this reason the writer believes that it is no longer employed.

The figure as it stands is liable to misinterpretation; if a small quantity of water has been used a high coefficient must necessarily result, even if no admixture whatever has taken place; and as the residual juice always contains less sugar than that already expressed, an accurate comparison on these lines is impossible.

3. *The Relation between Added Water per cent. on Canes and Dilution per cent. on Normal Juice.*— As the weight of the canes is greater than the weight of the normal juice, it might appear that the figure giving the added water per cent. on canes would be less than that giving the dilution per cent. on normal juice; a great part of the water added does not, however, enter into the mixed juice, but passes away with the megass, and with complete admixture the figure expressing the added water per cent. on canes will always be considerably greater than that expressing the dilution per cent. on normal juice. To obtain a comparative table of these figures one proceeds as follows: The degree Brix is taken as being uniform throughout the cane; let

the degree Brix be 18; let the canes contain 12 per cent. of fibre and be dry crushed to 45 per cent. of fibre, after which with complete admixture water 20 per cent. on cane is added, and the saturated megass crushed to 50 per cent. of fibre. In a dry crushing following on the equations already established there are obtained 73·33 parts of juice at 18 Brix per 100 cane; 14·67 parts of juice are left in the megass, which, when completely mixed with 20 parts of water, give 34·67 parts of diluted juice at 7·61 Brix; on crushing this megass to 50 per cent. of fibre there are obtained 22·67 parts of diluted juice at 7·61 Brix; this, when mixed with 73·33 parts of normal juice at 18 Brix, will give 96 parts of mixed juice at 15·55 Brix, and the dilution per cent. on normal juice is by the usual method of calculation 15·75 per cent.; the added water per cent. on cane at the same time being 20 per cent. In Table II., at at the end of this section, is calculated for single maceration and complete admixture the dilution per cent. on normal juice when water 10 per cent. to 50 per cent. is added to canes containing 12 per cent. of fibre and dry crushed to 45 per cent. of fibre, and after saturation to 50 per cent. of fibre.

Now if the admixture is incomplete, water passes into the mixed juice without carrying in the sugar which it was the object of its application to obtain, and the dilution will be higher than calculated above. Such a system of comparison gives, then, an idea of the efficiency of the added water, and may be used in the control or technical oversight of a mill, and it is to this end that the calculation has been introduced.

4. *A Method for expressing the Efficiency of the Added Water.*—A control or oversight of the useful effect of the added water is afforded, as has been shown above, by comparison of the figures expressing the added water per cent. on canes with the dilution per cent. on normal juice, and also by comparing the density of the last mill juice with the calculated figure when the admixture is complete. A more exact and definite comparison may be obtained by the use of the following methods :

In a plant employing a single maceration process, let the canes contain 12 per cent. fibre, and let them be dry crushed to 45 per cent. of fibre ; then on the lines already established, the extraction due to the dry crushing is 85·82 per cent. Let water 20 per cent. on cane be added to the dry crushed megass ; then with complete admixture and crushing to 50 per cent. fibre, a further extraction of 9·20 is obtained. Suppose the actually recorded extraction is 93·63 per cent.; then that due to the saturation is $93·63 - 85·82 = 7·81$. What may be termed the efficiency of the added water is then $\dfrac{7·81}{9·20} = ·849$; *i.e.*, the added water has extracted 84·9 per cent. of the maximum amount of sugar possible. To apply this formula in actual practice demands a knowledge of the fibre in the dry crushed megass, a determination that is not usually made ; perhaps in actual work it would be sufficient to determine the average

extraction due to the dry crushing process (varied, of course, as the fibre in the cane varies) and to use the figure so determined in the calculation of the efficiency of the added water.

Actually the amount of sugar extracted by mills falls short of that which with complete admixture would be obtained with a single maceration process ; the writer is of the opinion that the calculated figure for the extraction due to saturation in a single maceration process might be made the basis upon which the efficiency of the added water is expressed, independent of what system of maceration is employed.

TABLE I.

Giving the density of last mill juice in a single maceration process with complete admixture ; the dry crushed megass containing 45 per cent. of fibre, and cane containing 12 per cent. of fibre.

Degree Brix of Normal Juice.	WATER ADDED PER 100 CANE.								
	10	15	20	25	30	35	40	45	50
15	8·92	7·42	6·35	5·54	4·92	4·43	4·02	3·69	3·40
16	9·51	7·91	6·77	5·92	5·25	4·72	4·29	3·93	3·63
17	10·11	8·41	7·19	6·28	5·58	5·02	4·56	4·18	3·86
18	10·70	8·90	7·61	6·66	5·91	5·32	4·83	4·43	4·08
19	11·30	9·39	8·04	7·03	6·24	5·61	5·10	4·67	4·31
20	11·89	9·89	8·46	7·40	6·57	5·91	5·37	4·92	4·54
21	12·49	10·38	8·88	7·76	6·90	6·20	5·63	5·16	4·76
22	13·08	10·88	9·31	8·13	7·22	6·49	5·90	5·41	4·99

TABLE II.

Giving, for a single maceration process, the density of mixed juice and dilution per cent. on normal juice for canes containing 12 per cent. fibre, dry crushed megass containing 45 per cent. fibre, and saturated crushed megass 50 per cent. fibre. and normal juice containing 18 per cent. of solids.

Added Water per cent. on Cane.	Density Mixed Juice.	Dilution per cent. on Normal Juice.
10	16·92	6·38
15	16·23	10·90
20	15·55	15·75
25	14·89	20·88
30	14·27	26·14
35	13·69	31·49
40	13·15	36·88
45	12·65	42·29
50	12·18	47·78

Control of the Boiling House.—The basis of this is the amount of *available sugar* in the mixed juice, *i.e.*, that quantity of sugar which can be obtained from that expressed by the mills.

In times past a number of irrational formulæ based on the percentage of glucose and of ash have been proposed; the first rational one is that due to Winter who from a study of actually recorded results in Java concluded that one part of non-sugar prevented ·4 part of sugar crystallizing; expressed algebraically this observation appears

$$\text{Available sugar} = S \times \left(1\cdot4 - \frac{40}{\text{Purity}}\right)$$

where S is the amount of sugar in the raw juice. In this formula the available sugar refers to the gross weight of the commercial product.

The writer treats the matter as follows :—

In unit weight of a juice after removal of water let there be a parts of sugar and b parts of non-sugar. Now let c parts of sugar be removed as in the process of manufacture so that the residue (molasses) now is $1-c$; let $1-c$ contain d parts of sugar per unit weight. Since the total amount of sugar was a, the equation $a = c + (1-c)\,d$ results. Whence $\dfrac{c}{a} = \dfrac{(a-d)}{a\,(1-d)}$.

Now $\dfrac{c}{a}$ is the proportion of sugar that has been removed and for a, which is the proportion of sugar in dry material, the purity of the juice may be written and for d the purity of the molasses.

The expression then becomes

$$\left.\begin{array}{l}\text{Proportion of Sugar}\\\text{removed or Extraction}\\\text{of Sugar in Juice}\end{array}\right\} = \frac{\text{purity juice} - \text{purity molasses}}{\text{purity juice}\,(1 - \text{purity molasses})} = \frac{j-m}{j\,(1-m)}$$

where j and m are the purities of the juice and molasses.

That is to say when the purity of juice and purity of molasses are known, the corresponding extraction of sugar per 100 sugar in juice can be calculated.

The calculation above is an ideal one under conditions that are not reached in practice, assuming as it does that pure sugar and not an impure product containing a portion of the impurities is made; the impurities contained in the commercial sugar if replaced in the molasses would of course tend to lower the actually observed purity of the molasses. The complete formula can be obtained as follows :—

From a material containing a sugar and b non-sugar per unit weight, let there be removed c sugar and d non-sugar and let $(c + d)$ contain e sugar per unit weight. The residue (molasses) is $1 - c - d$ and let it contain f sugar per unit weight.

$$\text{Then } a = (c+d)\,e + (1-c-d)\,f \text{ or } \frac{c+d}{a} = \frac{a-f}{a\,(e-f)}$$

$$\left.\begin{array}{l}\text{or proportional gross weight of \textit{dry} commercial}\\\text{sugar removed}\end{array}\right\} = \frac{j-m}{j\,(s-m)}$$

where j and m are as before and s is the purity of the commercial product.

If the weight of *wet* commercial product is required, it is expressed by the formula :

$$\frac{j - m}{j\,(s - m)} \times \frac{100}{Brix\ of\ the\ Sugar}$$

The only reliable basis of calculation and method of comparison as between factories is, however, obtained by referring everything to pure sugar and we then have

$$Sucrose = \frac{(j - m)}{j\,(s - m)} \times \frac{100}{Brix} \times sucrose\ per\ cent.\ in\ commercial\ product = \frac{s\,(j - m)}{j\,(s - m)}.\ ^{*}$$

Expressed in words, this formula means that, with an initial purity of, say, 90, a purity of 98 in the product, and a purity of 45 in the waste molasses per 100 sucrose originally present, there is obtained of sucrose in the commercial product

$$100 \times \frac{98\,(90 - 45)}{90\,(98 - 45)} = 92 \cdot 45.$$

More sugar than this cannot possibly be obtained, and the nearer the actually recorded results come to the calculated ones, the less have been the losses of sugar in filter presses, in entrainment, &c.

In cane sugar practice it is usual to accept the direct polarizations of juice and sugars as giving the percentage of sucrose, and to use the Clerget process only for the waste molasses. For the proper application of this control *true* total solids and *true* sucrose determinations are essential, and these should find a place in the routine work of every sugar factory where accuracy is more highly considered than convenience. Difficulty arises in the application of this control in considering what should be taken as the initial purity, and whether the losses in press cake, entrainment, &c., should be considered as avoidable ; these losses are not necessary in the same sense that molasses losses due to the formation of a definite syrupy compound between sucrose and salts† are necessary, and in so far as they are determinable may be introduced into the equation as indicated below. As regards the initial purity introduced into the equation, that of the syrup might be taken as allowing for the removal of impurities in the press cake and in scale formed in the evaporators. The formula then appears as

$$Available\ sugar = (sugar\ in\ mixed\ juice - known\ losses)\,\frac{s\,(j - m)}{j\,(s - m)},$$

j, s, m being the true purities of the syrup, the commercial product, and the molasses respectively. The formula established above can be put in the form :

$$Commercial\ sugar\ per\ cent.\ on\ massecuite = \frac{B_m\,(j - m)}{B_s\,(s - m)},$$

where B_m and B_s are the total solids in the massecuite and sugar, and j, s, m are the purities of the massecuite, juice, and molasses.

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* Formulæ of similar form and obtained by different reasoning have been proposed by Winter, Geerligs, Rose, Carp, Lohman, and Hazewinkel in Java, between the years 1894 and 1903. A complete discussion of these is given by Geerligs in the Dutch edition of 'Cane Sugar and its Manufacture.'

† *Cf.* Chapter XIX.

Control of the Pan and Centrifugal Plant.—Following on what has been written in the chapter on the vacuum pan, the cardinal points in this control are the determinations of the sugar in crystal form, and of the actual water content of the massecuites and molasses. A comparison of the sugar actually present as crystals, with the amount obtained in the manufacturing process gives the amount lost either at a certain stage or totally lost in the waste molasses; this determination may be checked by analysis of the molasses as they actually leave the baskets, and of the same molasses after removal of fine grain by filtering through glass wool; this source of loss is to be looked for either in the pan (uneven grain due to lack of craft skill) or to the use of an unsuitable mesh in the centrifugal gauze.

The systematic determination of the water content of the massecuites, determining as it does the amount of sugar crystallized, is naturally of great importance.

A systematic record of the working of the massecuites should be kept; the data recorded by the writer when engaged in supervising a crystallization in motion plant included the following determinations:—

Date, number, density, volume, and weight of each strike; purities of the syrup and the molasses used and of the strike and purgings; dry matter in the strike and in the purgings; weight and polarization of the sugar obtained.

It may be mentioned that the apparent purities may be used in calculating the proportion of syrup and molasses to be used in making a strike. Success in this department depends very largely on an organized system of technical book-keeping.

Control of Entrainment Losses.—This term is usually taken to include all undetermined losses, and much of this is due to errors of analysis. Entrainment losses properly so called, due to sugar carried away mechanically in vapours from the boiling apparatus, are, with modern well-designed plants, reduced to a minimum; nevertheless the waste waters from the evaporators and pans should be systematically sampled and examined for sugar by one or other of the sensitive colour reactions; if any notable loss of sugar is indicated the same may be determined by the usual methods after evaporation to small volume of a large quantity of the suspected water.

Inversion Losses.—In a well-regulated factory these should be entirely absent, even when white or yellow crystals are being made; carelessness or the use of an excess of acid may lead to serious losses; it is perhaps impossible to estimate accurately these losses, since with alkaline juices there is a tendency towards the destruction of reducing sugars; hence any increase in the glucose over that initially present is to be regarded as pointing to an avoidable loss, the exact amount of which cannot be definitely stated.

Stock-takings.—At fixed intervals a stock-taking of all the factory products should be made ; the scheme used by the writer is as follows :—

	Tons.		Sucrose.		Per cent. on Sucrose in Cane.
Sugar packed	2367·2				
First massecuite estimated to give	43·1				
Syrup ,, ,, ..	8·3				
Juice ,, ,, ..	3·2				
Low massecuites ,, ,, ..	55·4				
	2477·2				
Less received from previous crop .	48·3				
Due to present crop	2428·9	..	2258·7	..	82·3
Previously	1910·8	..	1850·6	..	82·7
Current period	518·1	..	408·1	..	81·5

Expression of Results.—The writer is in favour of keeping two sets of accounts, one for the mill and one for the boiling house, since the processes in these two departments are radically distinct ; eventually these two sets should be combined and a final statement made, showing the yield and losses per 100 cane and per 100 sugar in cane.   A statement based only on cane and sugar in cane does not sufficiently specify the losses which, if excessive, may be due to bad mill work or to inefficient work in the boiling house.   The writer has spent much time in trying to draw up a scheme, that will include in one sheet all the necessary determinations, and has finally abandoned the idea in favour of keeping separate books for the mills, for the juices, and for the pans. The headings that should be systematically entered up are :—

Mills.   Weight of cane ; sugar per cent. in cane ; fibre per cent. in cane ; sugar obtained per 100 cane and per 100 sugar in cane ; dilution per cent. on normal juice ; water added per 100 cane ; efficiency of added water ; sugar per cent. in megass ; water per cent. in megass per cent. ; fibre per cent. in megass ; sugar in megass per 100 cane and per 100 sugar in cane.

Juices.—Total solids, sugar per cent. and purity of first mill, mixed, clarified, and last mill juices ; mixed juice per 100 cane ; sugar in mixed juice per 100 cane and per 100 sugar in cane ; available sugar with reference to the actually observed purities of clarified juice and of waste molasses.

Sugars.—Weight ; Sucrose per cent. ; weight of sucrose ; sucrose per 100 sucrose in juice, per 100 sucrose in cane and per 100 cane ; tons of cane per ton of sugar ; sucrose per 100 available sucrose.

Massecuites.—See above under the section headed ' Control of the Pan and Centrifugal Plant.'

Waste Molasses.—Total solids, sugar per cent. and purity ; weight ; weight per 100 cane ; sucrose per 100 cane and per 100 sucrose in cane and in juice.

Undetermined Losses.—Sucrose per 100 cane, per 100 sucrose in cane and per 100 sucrose in juice.

The exact way in which the forms are scheduled is so largely a personal matter, that the writer does not offer a scheme, but thinks it best to leave this to each individual interested.

Notes for Untrained Polarizers.—The following notes on laboratory work are intended for the use of factories where a resident chemist is not employed.

The Balance.—A chemical balance differs in no wise except in extreme sensibility from any commercial balance; but owing to the delicacy of its construction, it must be treated with extreme care; a few minutes use by a careless operator being sufficient to destroy its accuracy. Chemical balances are enclosed in tightly fitting cases with glass sides, access to the interior being given by a sliding door in front; the object of this is to protect the balance from damp and dust, and during weighing from draughts and other disturbing causes. As a further protection from damp, it is advisable to place in the balance a dish containing strong sulphuric acid or calcium chloride, which will absorb moisture and keep the inside of the case dry. A chemical balance consists essentially of an upright pillar, usually of brass, in which moves a second pillar which can be raised or lowered by turning a milled head screw; the top of the moving pillar is a plane surface of agate or highly polished steel; on this plane surface rests the beam which carries the pans; the beam is supported on the plane surface by a knife edge of steel or agate; the pans also hang on knife edges at the ends of the beams; when not in use the pans rest on the balance case, and by turning the milled head screw the beam and pans are raised, leaving the beam free to swing; from the centre of the beam passes vertically downwards a pointer, the end of which moves over a scale, and by observing the swing of the pointer the operator can tell when the beam itself swings evenly.

When weighing on a chemical balance, determinations as to whether exact balance is obtained are not made by letting the beam come to rest, but by observing if the pointer swings through equal angles; with a properly sensitive balance it would take too long a time to let the beam come to rest.

The weights used in the laboratory are always gram decimal weights; a set will contain one 50 gram, one 20 gram, two 10 gram, one 5 gram, one 2 gram, two 1 gram weights, and so on down to ·01 gram; weights smaller than this are so minute as not to be conveniently handled, and the following device is used:—The beam is divided into 100 equal parts, and a piece of wire, called a rider, weighing exactly ·01 gram, is arranged to be moved at will along the beam, its effect being proportional to its distance from the fulcrum.

Steel knife edges are unsuited for a damp tropical climate, and balances with agate fittings, though more expensive, are more satisfactory. The routine of weighing out, say, an exact quantity of sugar is as follows :—

1. See that the balance is in equilibrium, when the vessel destined to contain the sugar and the counterpoise supplied by the makers are in place, and if not, adjust with small pieces of tin foil.

2. The vessel to contain the sugar being on the left-hand pan, place on the right-hand pan the weight which it is wished to obtain, and approximately the desired quantity of sugar in the containing vessel, then adjust the quantity of sugar until balance is obtained. Never weigh any material directly on the pans, and never place or remove anything from the pans when the beam is free to move; the final adjustment should be made with the sliding door closed.

When weighing out large-grained sugars, an exact balance is difficult to obtain; in this case a little of the sample can be crushed and the final adjustment made with the powdered sugar.

The Burette.—A burette (*Fig. 274*) is a narrow cylindrical graduated glass tube provided with a cock at one end; by opening the cock any desired volume of liquid can be run out. For laboratory purposes the graduation is made in one-tenth of a cubic centimetre. Burettes are sent out by reliable dealers very accurately calibrated and no appreciable error need be looked for. The method of use is as follows : the

FIG. 274.

burette is rinsed out with the liquid to be used, filled and placed in a vertical position in the holder; the level of the contained liquid is adjusted by opening the cock until it corresponds exactly with some mark, say, 10·3; after a test has been made the level of the liquid is again noted, say, 27·6 c.c., showing that 17·3 c.c. have been used.

After use, if the burette is to be put away for any long period, the cock should be wiped dry and smeared with vaseline; if allowed to dry with the liquid remaining, the cock will probably become fixed, and efforts to remove it will possibly lead to fracture of the instrument.

The Pipette.—A pipette, *Fig. 275*, is a special form of burette designed to deliver one definite quantity of liquid. It consists of a narrow piece of glass tubing in the centre of which is blown a bulb; on the upper part of the stem is a mark. The pipette is filled by

FIG. 275.

suction, the lower end being immersed below the level of the liquid and the liquid aspirated up into the burette until a little above the level of the graduation mark; the filled burette is then smartly removed from the

mouth and the upper end closed with the finger; by raising the finger slowly the liquid is suffered to flow slowly out until the level of the liquid is coincident with the graduation mark, then by pressing the finger firmly down the flow is stopped and a definite quantity of liquid is contained in the pipette.

The first object of anyone working in a laboratory should be to keep all apparatus scrupulously clean; all burettes, pipettes, hydrometers, &c., after use should be rinsed with clean water and put to drain. Cleanliness is of especial importance in a sugar laboratory.

REFERENCES IN CHAPTER XXV.

1. *Chemical Engineer*, 9, 4.
2. *Bull.* 30 *Agric. H.S.P.A.*
3. *S. C.*, 1.
4. *S. C.*, 344.
5. *Bull.* 22 *Agric., H.S.P.A.*

CHAPTER XXVI.

FERMENTATION WITH SPECIAL REFERENCE TO THE SUGAR HOUSE.

This chapter treats principally of the fermentation of molasses and of the manufacture of rum; incidentally opportunity is taken to bring together some part of the scattered articles dealing with the mycology of the sugar house.

Yeast.—By this term is loosely meant any organism which has the property of fermenting sugars and producing mainly alcohol and carbon dioxide; in this sense organisms such as the *Torulae, Monilia,* and certain of the *Mucoraceae* would be included, although these organisms are very distinct from that mainly composing 'brewers' yeast,' which consists essentially of *Saccharomyces cerevisiae.* Systematically production of alcohol is not an essential character of the *Saccharomyces* although the greater number of species here included do produce alcohol; in addition some species ferment saccharose, dextrose, maltose; others dextrose and maltose only; others lactose only.

A complete list of all the known 'yeasts' is given by Kohl[1]; following him they are divided into these groups:—

I. Yeasts proper or budding yeasts. *Saccharomycetes.* These are divided into the following genera:—

1. *Saccharomyces;* 2. *Hansenia;* 3. *Torulaspora;* 4. *Zygosaccharomyces;* 5. *Saccharomycodes;* 6. *Saccharomycopsis;* 7. *Pichia;* 8. *Willia.*

II. Fission Yeasts, *Schizosaccharomycetes.* This includes one genus, *Schizosaccharomyces.*

III. Yeast like fungi. These are divided into the following genera:—

1. *Torula;* 2. *Mycoderma;* 3. *Monilia;* 4. *Chalara;* 5. *Oidium;* 6. *Dematium;* 7. *Sachsia;* 8. *Endomyces;* 9. *Monospora;* 10. *Nematospora.*

In European and North American breweries and distilleries alcoholic production is mainly produced by the species *S. cerevisiae;* a closely allied yeast *S. vordermanii* is responsible for most of the alcohol produced in tropical countries from molasses; in addition, fission yeasts have been observed in the Antilles[2], in Jamaica[3], in Natal[4], and in Peru[5]; they are of great importance in the production of rum, but have not received the extended study that has been given to the budding yeasts.

Yeasts of special Interest in Connection with Rum Distilleries.—The first detailed study of any yeast in connection with the cane sugar industry is that due to Went and Geerligs[6], who isolated from *Raggi* or Java yeast a species which they named *S. vordermanii;* this is a typical budding yeast.

In 1893 Greg[3] isolated from Jamaican distilleries a fission yeast, *Sch. mellacei*; it is very similar to the first observed fission yeast isolated from Kaffir millet beer in Natal; this has been named *Sch. pombe* and described by Lindner[4].

Peck and Deerr[5] collected yeasts from molasses distilleries in Demerara, Trinidad, Mauritius, Natal, Cuba, Java, and Peru; all except the last were budding yeasts, very close if not identical with *S. vordermanii*; the yeast from Peru was a fission yeast very close to *Sch. pombe*.

In *Figs. 276* and *277* (*see* PLATES XXI. and XXII.) are shown the yeasts collected by Peck and Deerr. *Fig. 276* shows the yeasts 36 hours old in beer wort, the reference being as to district of origin : 1, Java ; 2, a non-sporing yeast from Natal, peculiar for its production of ethereal salts and referred to in the text ; 3, Trinidad ; 4, Natal ; 5, Demerara ; 6, Natal ; 7, Cuba ; 8, Mauritius ; 9, Peru. The septum across which the Peruvian yeast divides is not shown ; division occurs symmetrically at right angles to a longitudinal axis. *Fig. 277* shows the same yeasts sporulating, the district of origin being indicated by initial letters ; the sporulation was obtained on gypsum blocks, except for the Peru fission yeast, which was obtained from an old agar beer wort plate culture.

It may then be said that the production of rum proceeds under the influence of *S. vordermanii* and *Sch. pombe* either separately or conjointly, the fission and budding yeasts having been found together in Jamaican distilleries. Of the other *Saccharomyces* the type represented by *S. mali Duclauxi* is of interest. This species does not ferment saccharose and it has hence been used by Pellet and Perrault[7] to remove glucose from molasses in analysis; its use on the economic scale has been patented by McGlaschan[9] with the idea of obtaining an increased yield of sugar.

Wild Yeasts.—By this term is meant a yeast other than the one desired in any particular fermentation ; the term has a special significance when used in connection with a pure culture process, *i.e.*, one in which the fermentation is intended to be carried on by one specific organism to the exclusion of all others ; in a sense since the presence of yeast in molasses is adventitious, molasses fermentations might be regarded as carried on by wild yeasts.

Other Organisms connected with Fermentation.[9]—
Perisporaceae.—This is an extensive order of fungi including amongst others the well-known genera of *Aspergillus* and *Penicillium*, both of which are of cosmopolitan distribution ; they have been studied chiefly in connection with their action on grain and wines to which they give an unpleasant flavour. *Aspergillus oryzae* is of interest as being the organism, to the diastatic action of which is due the saccharification of rice starch in the preparation of the Japanese spirit Saki ; *Penicillium glaucum* has been connected by Shorey[10] with the deterioration of sugars.

Mucoraceae.—The *Mucoraceae* or pin moulds are of frequent occurrence as objectionable organisms in distilleries; some of them can produce limited quantities of alcohol. *Mucor oryzae*, which is perhaps the same as *Rhizopus oryzae*, was isolated by Went and Geerligs[9] from Raggi; this fungus can saccharify starch, but does not produce alcohol. *Mucor Rouxii*, isolated from Chinese yeast, has enjoyed some notoriety as an economic alcohol producer, but does not now seem to be a likely rival to the *Saccharomyces*.

Fungi imperfecti.—By this term is meant those fungi the classification of which is uncertain; included here are the *Torulae* (by which term is now meant a non-sporing yeast-like organism fermenting sugar) and the *Mycordermae* or true film fungi connected with the oxidation of alcohol to acetic acid. *Monilia iavanica* was isolated by Went and Geerligs[9] from Raggi; it produces up to 5 per cent. of alcohol to which it gives an unpleasant taste. An allied organism, isolated by Peck and Deerr[5] from a Natal distillery, was remarkable for its high production of acetic and butyric ethers, as much as 7558 parts ethers as acetic ether being produced per 100,000 of alcohol.

Bacteria.—Numerous bacteria are connected with the sugar fermentation industries; a systematic account of such as have been studied herewith is quite without the limits of the present work. It may be at once stated that generally bacteria are a prolific source of disease and loss in distilleries, especially in rum manufacture, although as shown later in grain distilleries at one stage their presence is essential; to their presence may be attributed imperfect attenuations and low returns. Some particular types of bacterial activity of greater interest are briefly mentioned below, and it must be remembered that in all cases the types of fermentation referred to in a heading may be brought about by any one of a number of distinct organisms.

Lactic Acid Fermentation.—The importance of the bacteria which produce lactic acid in green malt in cereal distilleries is shown in a subsequent section; they occur chiefly in sour milk and in green malt; through their agency the production of lactic acid from beer wort has been proposed, and its production from molasses does not seem *prima facie* impossible; certain species have been noted as causing disease in beer.

Acetic Acid Fermentation.—This fermentation is economically of importance in the production of vinegar from alcohol; it may take place under the influence of certain well defined bacteria or under that of an imperfect fungus, referred to as *Mycoderma vini;* generally it is essentially a process of oxidation, but Watts and Tempany have shown that the spontaneous souring of cane juice proceeds anaerobically, the sugar forming the source of oxygen. Acetic acid has been observed by Grieg Smith[11] in soured sugar, and sugar or juices left in crevices about a sugar factory undergo this fermentation and are responsible for the sour smell often observed; wash kept after the alcoholic fermentation is complete also undergoes acetic fermentation, and the

writer has knowledge of cases where consignments of 'molascuit' completely underwent this fermentation in transit between Demerara and London.

Butyric Acid Fermentation.—This fermentation is technically of importance in the rum industry as the flavour of fine rum is by some authorities believed to be intimately connected with its presence; in cereal distilleries it is considered most harmful, as not only does it decrease the yield of alcohol but also forms objectionable products as butyric acid and butyl alcohol.

Viscous Fermentation.—This term has now only an ill-defined meaning, but occurs frequently in older writings on fermentation; it is used in reference to fermenting liquids becoming ropy or slimy, and was once not an uncommon phenomenon; in European distilleries this disease has been associated with certain well-defined bacterial species; in rum distilleries it is not unknown and may often be traced to lack of cleanliness and to attempting to work with too little or no bactericide.*

Gumming.—The 'gumming' of cane juices has been studied by Greig Smith,[12] who found that this was due to a bacillus which he described and named *Bacillus levaniformans*; this organism is also one of several responsible for the deterioration of sugars; Lewton Brain and Deerr[13] isolated from Hawaiian sugars several forms which also produced large quantities of gum; formerly this fermentation would have been classed as a 'viscous fermentation.'

Leuconostoc Mesenterioides.—This organism, known as 'frog spawn,' has the faculty of converting sugar solutions into a gelatinous, viscous mass; it is a well-known type and has been reported from Europe and Java where it has been the cause of blocking up pipes used for the conveyance of juices.

Spontaneous Fermentation of Cane Juice.—Watts and Tempany[14] found that yeasts and an undetermined bacterium were concerned in this process; alcohol was produced by the yeast and acids by the bacterium, of which about one third were volatile acids; the fermentation was both aërobic and anaërobic, and was inhibited by the presence of phenol indicating that already formed enzymes do not play a very prominent part in the souring of juices.

Spontaneous Combustion of Molasses.—Crawley[15] has recorded a case of molasses on storage becoming charred, the damage being supposed to to have been initially due to micro-organisms; consignments of 'molascuit , have suffered a similar change on board ship.

Nitric Fermentation of Molasses.—In beet sugar factories the after massecuites on storing sometimes show a nitric fermentation. A dense red cloud of vapour due to the presence of nitrogen dioxide is observed to hang over the massecuites; this is ascribed to decomposition of the potassium nitrate present under the influence of bacteria, but really very little is known on the subject. The writer is unaware of any similar phenomenon being observed in cane sugar factories.

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* The use of bactericides in distilleries is explained in a subsequent section.

Foaming of Massecuites.—Geerligs[16] explains the foaming of stored massecuites as due to the spontaneous decomposition of glucinic acid formed by the action of lime on reducing sugars. Ashby,[17] however, has in Jamaica isolated a yeast which is active in concentrations up to 80° Brix, and attributes the phenomenon to the presence of these organisms.

Faulty Rum.—By faulty rum is meant a spirit which on dilution with water becomes cloudy and throws down a deposit. The causes to which this behaviour are attributed are :—The presence of caramels soluble in strong and insoluble in dilute spirit ; the presence of higher fatty acids, due to careless distillation, which are precipitated on dilution; the presence of terpenes extracted by the spirit from the casks ; the presence of a micro-organism capable of life and reproduction in 75 per cent. alcohol; the latter view was brought forward by V. H. and L. Y. Veley[18] who named the supposed organism *Coleothrix methystes* and stated that it is extremely resistant to ordinary methods of destruction, survives desiccation, is air borne, and both aërobic and anaërobic ; in certain of their publications the organism is described as multiplying and living actively in 75 per cent. rum and in other places as merely surviving in spirit. The whole of the results of V. H. and L. Y. Veley were challenged by Scard and Harrison,[19] who were unable to obtain any of the effects noticed by the Veleys. They found, however, in Demerara rums remains of organisms similar to the one in question, and were of opinion that faultiness in rum was due to the first three causes mentioned above.

When rum samples have been kept in an imperfectly sealed bottle so that the spirit is free to evaporate, the writer has frequently noticed a slimy mucinous growth appear ; this on microscopic examination is found to be of a fungus character, and to be similar to that described by Veley as the cause of faulty rum. The writer has never observed it in strong spirit, but when the fungus growth was transferred *en masse* to 75 per cent. alcohol, the organisms were not killed but cultures could be obtained for over a year ; the growth did not increase in size but remained suspended in the rum, which remained quite clear ; when a drop of the original weak spirit containing the fungus was inoculated into sound clear rum, no change whatever took place. The writer thinks it quite possible that masses of the organism, to the existence of which he gives credence, have found their way into casks and puncheons, and have thus been present and alive on arrival in England, but does not think they can be called the cause of faulty rum.

Deterioration of Sugars.—The deterioration of sugars on storage is without doubt to be attributed to the action of micro-organisms. Shorey[10] attributed it chiefly to the action of mould fungi, but more recent studies lead to the conclusion that bacteria are mainly responsible. Grieg Smith[20] was inclined to attribute the damage to one specific organism, *Bacillus levaniformans*, which he found originally in Australian juices and sugars and afterwards in sugars of cosmopolitan origin ; this organism is char-

acterized by the abundant formation of a gum 'levan.' Lewton-Brain and Deerr[13] isolated five forms of bacteria from Hawaiian sugars, all of which were capable of causing deterioration; of these five it was found that three were remarkable for the formation of a gum similar in properties to 'levan,' and these forms were the most dangerous. Norris and Deerr[13] showed that sugars containing less than 1 per cent. of water were not liable to deterioration, and Lewton Brain and Deerr proved that sterile sugars under conditions favourable to deterioration remained unchanged. Bacteria, as a cause of deterioration, have also been observed by Geerligs in Java. The prevention of deterioration is best effected by the prevention as far as possible of contamination of the products, as by rapid working (*e.g.*, crystallization in motion), the use of antiseptics about gutters and containers, the use of sterile water at and about the centrifugals, and by controlling the amount of water in the final product.

In Java the bags have been noted as a source of infection, but gunny bags from Indian jute mills examined in Hawaii by Norris and Deerr[21] were sterile.

It has been shown by Watts and Tempany[22] that bacterial action in muscovado sugars may actually cause a rise in polarization; in this case the levulose is first selected for attack.

Fermentation Changes in Massecuites.—Browne[24] has investigated the nature of the scum which is often seen to rise on to the surface of stored massecuites to which he attributes a fungus origin; he obtained from this scum *chitine*, a fat very similar in composition to butter fat; he also reports encountering dimethyl ketol in sour molasses.

Manufacture of Rum.—The manufacture of rum as a product of the fermentation of cane juice or of molasses forms an important part of the cane sugar industry in Demerara, Trinidad, Jamaica, Cuba, the Leeward Islands, the French West Indies, Hayti, and the Argentine; rum is also manufactured in connection with sugar mills in Peru, Mauritius, Queensland, and Natal. Molasses form the source of the spirit 'arrack' in Java, and are also utilized in British India; in these two localities however the manufacture of spirit is divorced from the sugar industry proper. The writer has been unable to obtain statistics of the annual production of rum, but believes the total production cannot be less than 20,000,000 gallons of spirit containing 75 per cent. of alcohol.

Outlines of the processes used in different localities follow.

Demerara.—A process of adventitious fermentation obtains; commercially exhausted molasses form the initial product; the molasses are received directly from the centrifugals, storage for a few days' supply only being provided. The molasses and water—generally trench water—are usually mixed to the required density in a mechanical mixer in the basement and pumped up to the vats in the fermenting loft; in other cases the molasses are pumped up to the vat and mixed by hand with the requisite amount of water; the density
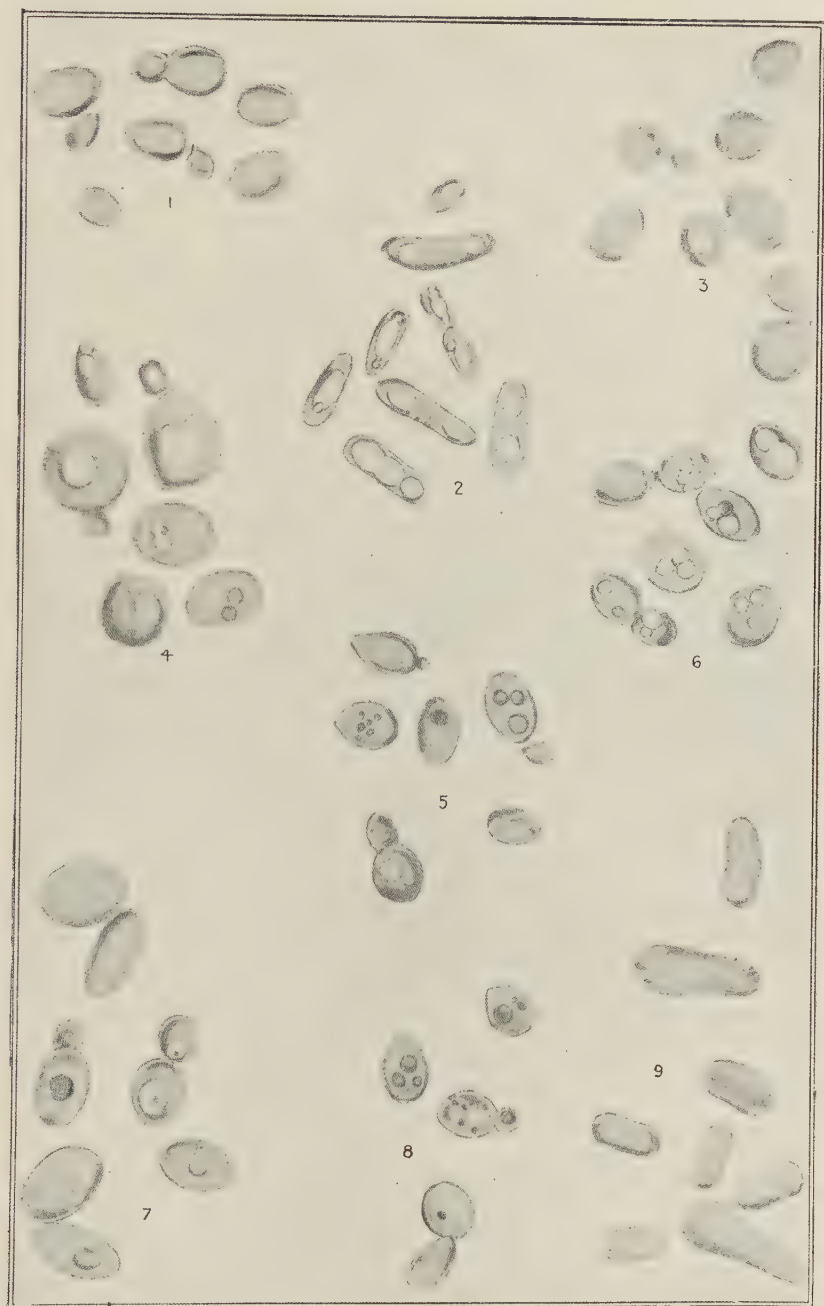
PLATE XXI.

FIG. 276.

Plate XXII.
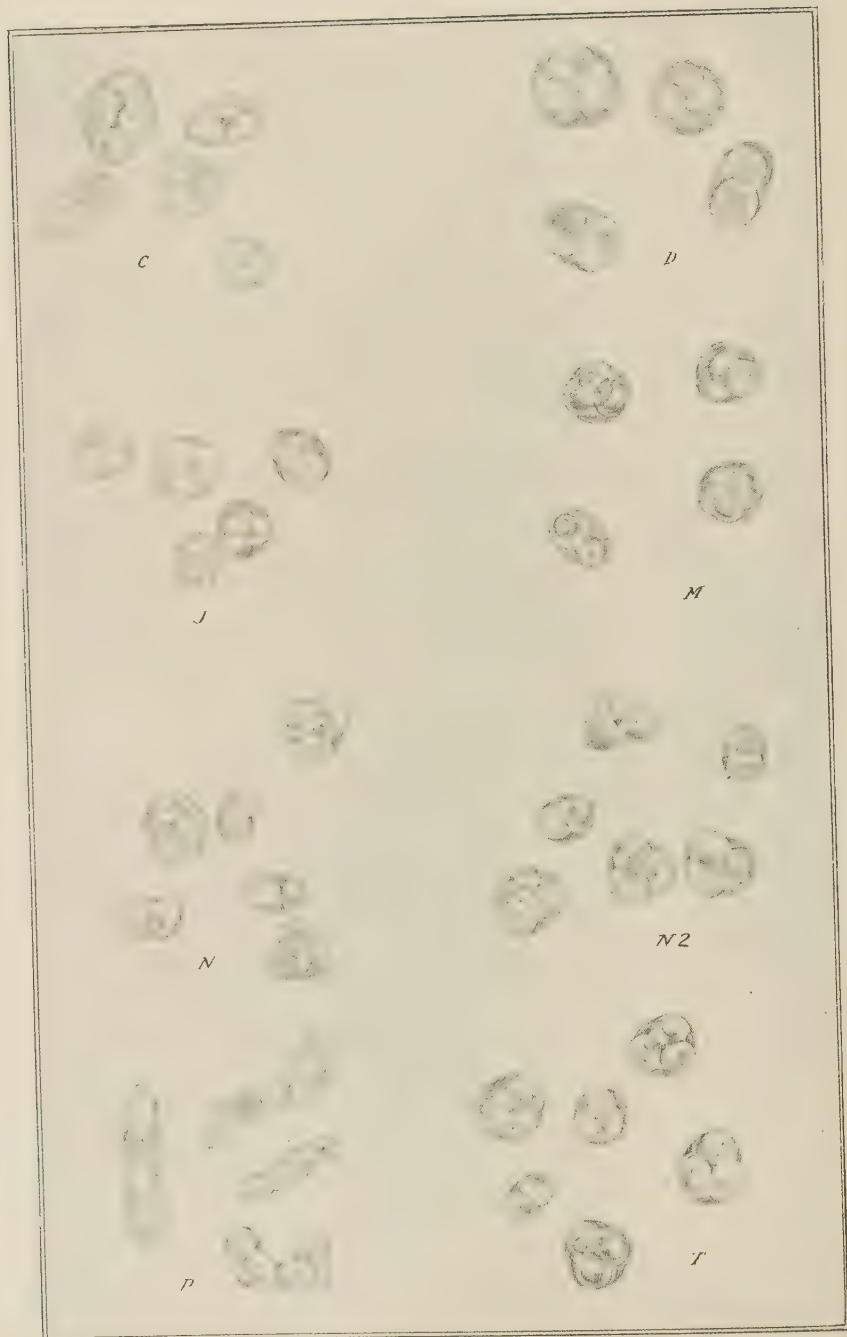
Fig. 277.

of the mixture varies from 1·060 to 1·063 ; to the wash is added sulphuric acid and sulphate of ammonia in the proportions of 1 gallon and 10 lbs. per 1000 gallons ; the acid is added to prevent the growth of bacteria, especially the 'butyric acid' forms; fermentation sets in rapidly, and is generally complete in 48 hours ; the density of the fermented wash varies from 1·015 to 1·025, and is governed by the amount of sugar present and the action of the yeast ; in some distilleries ammonium bifluoride is used as a bactericide in place of sulphuric acid. This simple process is the one that generally obtains elsewhere.

Mauritius.—In this district only one sugar factory possesses or did possess (1901) a distillery as an annex ; the process there followed is as under :—A barrel of about 50 gallons capacity is partly filled with molasses and water of density 1·10 and allowed to ferment spontaneously ; sometimes a handful of oats or rice is placed in this as a preliminary to fermentation. When attenuation is nearly complete, more molasses are added until the contents of the cask are again of density 1·10, then again allowed to ferment. This process is repeated a third time ; the contents of the barrel are then distributed between three or four tanks, holding each about 500 gallons of wash of density 1·10, and 12 hours after fermentation has started here, one of these is used to pitch a tank of about 8000 gallons capacity ; a few gallons are left in the pitching tanks which are again filled up with wash of density 1·1, and the process repeated until the attenuations fall off, when a fresh start is made. This process is very similar to what obtains in grain distilleries save that the initial fermentation is adventitious.

Java.[24]—In Java and the East generally, a very different procedure is followed. In the first place a material known as Java or Chinese yeast is prepared from native formulæ. In Java, pieces of sugar cane are crushed along with certain aromatic herbs, amongst which galanga and garlic are always present, and the resulting extract made into a paste with rice meal ; the paste is formed into strips, allowed to dry in the sun, and then macerated with water and lemon juice ; the pulpy mass obtained after standing for three days is separated from the water and made into small balls, rolled in rice straw and allowed to dry ; these balls are known as *Raggi* or Java yeast. In the next step rice is boiled and spread out in a layer on plantain leaves and sprinkled over with Raggi, then packed in earthenware pots and left to stand for two days, at the end of which period the rice is converted into a semi-liquid mass ; this material is termed *Tapej* and is used to excite fermentation in molasses wash. The wash is set up at a density of 25° Balling and afterwards the process is as usual. In this proceeding the starch in the rice is converted by means of certain micro-organisms, *Chlamydomucor oryzae*, into sugar and then forms a suitable habitat for the reproduction of yeasts, which are probably present in the *Raggi*, but may find their way into the *Tapej* from other sources. About 100 lbs. of rice are used to pitch 1000 gallons of wash.

Jamaica.—Allan[25] gives the following outline of the process followed in making flavoured spirit :—"The wash is set up from skimmings, dunder, molasses, acid and flavour. Acid is made by fermenting rum cane juice which has been warmed in the coppers. To this juice is added dunder and perhaps a little skimmings. When fermentation is about over, the fermenting liquor is pumped on to cane trash in cisterns and here it gets sour. Into these cisterns sludge settling from the fermented wash is from time to time put. This acid when fit for use smells like sour beer. Flavour is prepared by running fermented rum cane juice into cisterns outside the fermenting house along with cane trash and dunder that has been stored from a previous crop. Generally a proportion of liquid from what is called the 'muck hole' is also added to this cistern. The components of the 'muck hole' are the thicker portion of the dunder from the still, the lees from the retorts, and cane trash and other adventitious matter which from time to time finds its way into this receptacle. From this cistern the incipient flavouring material passes on to a second and third cistern filled with cane trash, and to which sludge from fermenting wash has been added. From the third cistern it is added to the wash. Skimmings are run from the boiling house into cisterns half filled with cane trash. This is allowed to remain four, five, or six days. When the skimmings are considered ripe, wash is set up with them. Fermentation lasts seven to eight days. The time which elapses between setting up the wash and distillation is from thirteen to fourteen days."

Process used in Grain Distilleries.[24]—It is of interest to compare the above methods with those in use in cereal distilleries. The basis of manufacture is grain ; this is ground to a coarse powder and a weighed amount is placed in a digester mixed with water and heated by steam under a pressure of two or three atmospheres for an hour or more ; the liquid contents of the digester are then blown into a second vessel and cooled ; as soon as the temperature falls below 63° C., a proportion of malt is added ; the malt contains a ferment, diastase, which converts the starch in the grain to a sugar, maltose ; after the starch has been converted into maltose, the contents of the vat are drawn off into a fermenting vat and rapidly cooled ; the vats are usually large enough to hold a whole day's work, and a distillery will have generally six fermenting vats, each of which may be of as great a capacity as 50,000 gallons. After the vat is set up it is *pitched* with yeast, and the temperature and quantity of yeast regulated with the object of obtaining the maximum yield of alcohol within the legal limit of time, *i.e.*, 72 hours. The temperature is regulated by means of water circulation through coils and maintained at 20°–25° C. ; the high temperature promotes a rapid fermentation, but more fusel oils are formed than at a low one.

The preparation of the pitching yeast is as under :—A mixture of green malt and water is warmed to about 70° C., kept at this temperature for about two hours to allow the starch to be converted to maltose and *soured*. Green

malt contains enormous numbers of bacteria, amongst which are the lactic and butyric acid organisms ; butyric acid is a virulent yeast poison, and its development would injure the yeast ; these organisms cannot be killed by raising the temperature as this would also destroy the action of the diastase. The butyric acid bacteria are, however, themselves susceptible to slight degrees of acidity ; in order to destroy them without injuring the yeast the temperature is arranged so that the lactic acid bacteria can develop ; the optimum temperature of the lactic acid bacteria is from 47° C. to 50° C., that of the butyric acid organisms about 40° C. The mash is hence kept at a temperature of about 50° C., whereby the lactic acid bacteria thrive and the formation of lactic acid effectually prevents the development of the butyric acid organisms. When the acid present reaches 1·0 to 1·1 per cent., the process is stopped by raising the temperature to 70° C. ; the mash is re-cooled to 20° C. and pitched with yeast, in the proportion of about 1 lb. to 10 gallons ; after about 14-16 hours the yeast has so far developed as to be used in the main process, a portion being kept for the next sour mash.

This process left much to chance, and has been developed on other lines although the object in view has always been the same. In the first place the presence of lactic acid bacteria is adventitious, and although their presence is very general, it not infrequently happened that the process miscarried by reason of their absence ; to get over this difficulty the infection of the sour mash was carried out by innoculation with pure cultures of lactic acid bacteria, and now more recently a new process known as the hydrofluoric acid process has been largely introduced.

It was sought for a long time to find some substance that would be antiseptic to the butyric acid bacteria and yet harmless to the development of yeast, and after many bodies had been tried Effront, in 1890, introduced the use of alkaline fluorides. The initial proposition was to add from 4 to 8 grms. of hydrofluoric acid per hectolitre (say from $\frac{1}{20} - \frac{1}{10}$ lb. per 100 gallons) of the yeast mash which had been treated in the way described above, this quantity being found sufficient to prevent the development of injurious organisms.

Composition of Rum.--Rum has now been defined as a spirit distilled from fermented products of the sugar cane in a country where the sugar cane is grown. This definition shuts out the use of the term for spirits distilled from cane molasses imported to Europe or North America, and does not differentiate between a juice and a molasses spirit ; originally the term rum was applied to the former and tafia to the latter.

Rum consists mainly of alcohol and water, the other bodies present being caramel (in coloured rums), fatty acids, ethereal salts, aldehydes, higher alcohols and essential oils ; the acids known to be present are formic, acetic, butyric, and capric, both free and as ethereal salts. Miller[26] has given the following analyses of Demerara rums :—

ANALYSES OF DEMERARA COLOURED RUM.

	PERCENTAGE BY VOLUME.								
	1	2	3	4	5	6	7	8	9
Alcohol	80·84	80·40	79·19	77·39	76·68	80·56	77·32	80·98	80·19
Higher alcohols, "fusel oil" . .	·8956	·7975	·4557	·5903	·6942	·6463	·3218	·9243	·1581
Ethylic formate .. .. :	·0088	·0155	·0405	·0373	·0233	·0396	·0180	·0373	·0350
Ethylic acetate.. .. .. :	·0243	·0231	·1258	·1563	·0645	·1018	·0542	·0636	·1229
Ethylic butyrate .. .. :	·0101	·0334	·0499	·0510	·0115	·0302	·0165	·0186	·0661
Total acid (as acetic) .. .. :	·148	·190	·196	·160	·196	·160	·166	·131	·136
Volatile acid (as acetic)	(·018)	(·018)	(·060)	(·024)	(·030)	(·016)	(·024)	(·021)	(·015)
Total solids (colour) .. .. :	1·040	1·210	1·750	1·510	1·420	·990	·1750	·680	·1050
Potash (K_2O) absorbed by colour ..	(·1974)	(·2128)	(·2820)	(·2162)	(·2068)	(·1795)	(·2256)	(·1955)	(·1974)

Micko[27] has given, amongst others, the following analyses of genuine and fictitious Jamaica rums of ascertained purity.

Specific Gravity at 15.5°C.	Alcohol per cent. by Volume	Volatile Acids, as Acetic. Grms. per 100 c.c.	Ethers, as Ethyl Acetate. Grms. per 100 c.c.	Flavouring Constituent of genuine Jamaica Rum.	Flavouring Bodies foreign to Jamaica Rum.	Coal Tar Dye Stuff.	Taste and Aroma.	Remarks.
·9440	44·9	·0036	·070	None	Vanillin	No	Of artificial rum	Artificial rum
·9452	44·2	·0280	·071	,,	,,	,,	,,	,,
·9361	49·3	·0024	·040	,,	,,	Yes	,,	Artificial rum with small proportion of Jamaica rum
·9448	44·5	·0110	·058	Trace	,,	No	,,	,, ,,
·9100	61·7	·0110	·090	,,	Cassia oil	,,	,,	,, ,,
·9347	50·0	·0051	·018	Present	Vanillin	,,	Not of pure Jamaica rum	Artificial rum with Jamaica rum
·8793	74·4	·0390	·378	Large amount	No	,,	Of Jamaica rum	Pure Jamaica rum
·8813	73·7	·0430	·799	,,	,,	,,	,,	,,
·8886	71·2	·0642	·396	,,	,,	,,	,,	,,

Geerligs[28] has given the following analyses, amongst others, of Batavian rums (arrack).

	Alcohol per cent. by Volume.	Free Acid.	Ethers.	Aldehydes.	Furfurol.	Higher Alcohols.	Total Non-Alcohols.
				PARTS PER MILLION.			
Batavia arak prima	60·7	1500	2464	591	50	250	4858
,, ,, K.W.T.	59·4	1500	2464	352	50	500	4866
,, ,, B.A.M.	58·4	1310	2552	298	90	440	4690
Rum from British India X	50·2	50	440	132	0	850	1604
,, ,, ,, XX	52·5	24	610	88	0	800	1484
,, ,, ,, XXX	52·4	50	528	132	0	750	1372

In consequence of an abortive prosecution for selling Demerara rum as Jamaica rum, Harrison[29] examined the ethereal salt content of Demerara rums, finding a variation from 23·7 to 141·6, with a mean of 64·7 parts per 100,000; pot still rums contained on an average 69·9, and continuous still rums 44·9 parts per 100,000 of alcohol.

In Jamaica rums, classed as 'common clean,' Cousins[30] found 200-300, in high-class ordinary rums 300-400, and in the best flavoured 1100 and upwards parts ethereal salts per 100,000 of alcohol.

The Flavour of Rum.—It is generally held that the peculiar fruity flavour of rum is due to the presence of ethyl ethers, particularly the butyrate and caprylate. It has been shown by Cousins that these ethers, particularly the latter, are present in very minute quantity, and that the ether predominantly present is the acetate; compared with the other ethers the acetate and butyrate, particularly the former, are volatile and these serve as a means whereby the heavier ethers are conveyed to the organ of smell. According to the same writer the accentuation of the flavour on dilution is due to the presence of water decreasing the volatility of the acetate thereby masking its somewhat pungent yet pleasant smell. These remarks apply exclusively to Jamaica rums, and not to Demerara rums of less ether content; in these Harrison[29] claims that the peculiarities are in some part due to the caramel compounds used in colouring.

The origin of these ethers is connected with the process of manufacture followed; Allan[31] considers that the factors are the presence of fission yeasts, of butyric acid forming bacteria, of which he has isolated one, and of *Bacillus mesentericus*, to which is attributed the presence of higher alcohols, especially butyl alcohol; Allan's work refers to Jamaica rums, and bacteria could play only a very small part in the development of flavour in the quick fermentation process followed in Demerara, where indeed bactericides are used to inhibit their action.

That the budding yeasts have but little to do with the development of flavour in rum is probable from the results of Peck and Deerr,[5] who found in pure culture that only 18 parts of ether (as acetate) were formed per 100,000 of alcohol, and previously Deerr had observed no special flavour when cultivating in pure culture fourteen Demerara yeasts; with the fission yeast Peck and Deerr isolated from Peruvian material no special flavour was observed; from Natal material they obtained, however, a Monilia, which produced a slow alcoholic fermentation, and at the same time formed 7558 parts ethereal salts (as acetate) per 100,000 of alcohol, both acetate and butyrate being present; to this or to a similar organism they suggested the origin of ethers in high-class rums. About the same time Ashby[32] found a 'fruit ether producing yeast' in Jamaica distilleries. Micko[27] by means of fractional distillation has established the presence in Jamaica rum of a body which is not an aldehyde, ketone or ester, but has the properties of an ethereal oil, though it may be allied to

the terpenes, and to this he attributes the peculiar flavour of Jamaica rum, utilizing its absence and presence as diagnostic of the authenticity. Notwithstanding, the presence of ethereal salts is a very large factor in forming the flavour and bouquet of rums.

The sharp unpleasant taste of freshly distilled rums is probably due to the presence of fatty acids; these in time react with the alcohol forming ethereal salts, an equilibrium between alcohol, fatty acid, ethereal salts and water being formed; to this is perhaps due the ageing of spirits.

It is stated that, in Jamaica, fruits such as mangoes, pine-apples, guavas, are mixed with the wash so as to impart their flavour to the spirit, but of this the writer has no first hand knowledge; it has also been stated that old boots and tobacco are used to flavour Jamaica rum, but this a gross miss-statement and entirely without foundation.

The addition of laboratory prepared ethereal salts to silent spirits with intent to imitate genuine rums is, of course, a fraud.

Various patents employing ozone, electricity, &c., with the idea of rapidly ageing spirits have been taken out, but the writer is unaware of the successful application of any one of them.

The Distillery.—A distillery consists of four separate buildings; the liquor loft containing the fermenting vats, the still house in which are placed the stills, the engine house and the rum store; to these in certain cases may be added the boiler house.

The choice of position for the liquor loft is not unimportant, as experience has shown that the fermentation is affected by apparently trivial causes; it should be raised on pillars about fifteen feet from the ground, be well lighted and ventilated and open on all sides to the breeze, and should not be shadowed by the other factory buildings. In certain factories the rum store is built underneath the liquor loft; this is inadvisable as besides running the risk of wash leaking into the rum vats, circulation of air underneath the liquor loft is prevented. The pipes and gutters used in connection with the distillery should be placed and arranged so that they present easy access for cleaning; underground pipes, and concrete or brickwork tanks in connection with a distillery are unhesitatingly to be condemned.

The number of vats and their capacity depends on the amount of molasses available and the time required for fermentation; every 100 gallons of molasses will give between 600 and 700 gallons of wash at a density of 1·060, and from every 100 tons of sugar made, from 3000 to 9000 gallons of molasses result, dependent of course on the composition of the juice. Given 100 tons of sugar per week, from 3000 to 9000 gallons of wash per day will be produced, and allowing the fementation to take 48 hours, the capacity of the vats must be double this; in practice it would be advisable to allow at least 25 per cent. in excess of the calculated figure. Of course in many places

a longer period than 48 hours is taken in the fermentation, and then a corresponding increase in the capacity of the vats must be allowed. A usual size of vat found in the West Indies is one holding about 3000 gallons; in Scotch and English distilleries much larger vats are the rule and a capacity of 50,000 gallons is not unusual; the initial cost of erecting a few large vats, and a loft to contain them and cost of upkeep, is less than for a larger number of small vats, and it is a general opinion that a slightly better fermentation is obtained in larger vats.

Antiseptics should find a larger use in distilleries, especially when shut down; all gutters, pipes, &c., should be carefully cleansed. The antiseptic most in use in Europe now is a 1 per cent. solution of ammonium fluoride; fresh
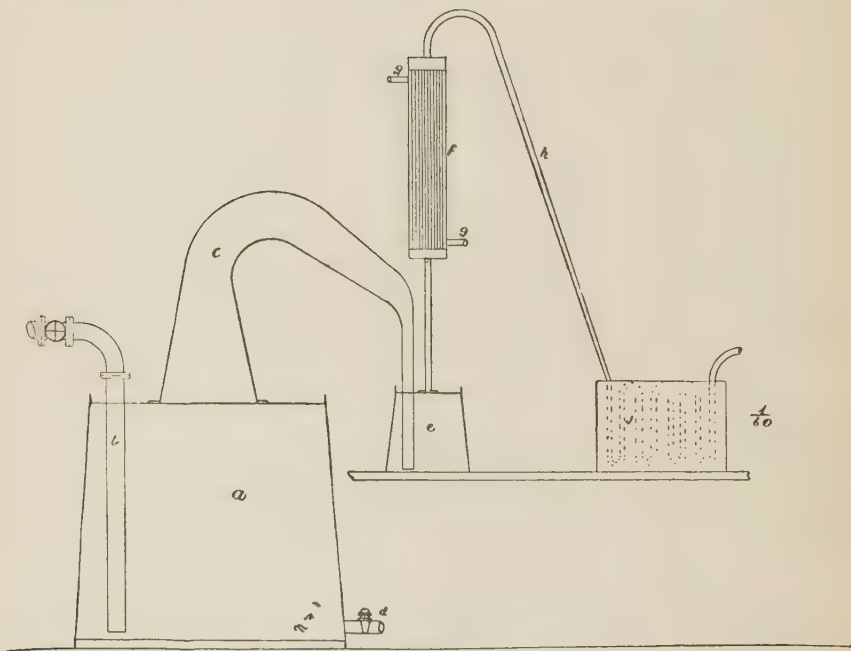
FIG. 278.

milk of lime is, however, an efficient cleanser and it will be found sufficient if all vats and other places, which come in contact with sweets, be washed down on ceasing operation with milk of lime.

Forms of Stills.—The stills used may be divided into two classes, direct fired and steam stills, or again into intermittent or continuous stills. Direct fired stills are very uncommon and only a few remain in unprogressive districts; they are constructed of copper and set in brickwork over a furnace with a circular flue; besides being expensive as regards first cost they are very uneconomical in fuel consumption.

Vat Still.—A sectional view of the general form of a steam-heated vat still is given in *Fig. 278*; *a* is a wooden vat of capacity varying with the amount of wash to be treated; at *d* is shown the pipe through which the lees are discharged when the wash is exhausted; steam from the boilers is admitted by the pipe *b*, which reaches nearly to the bottom of the vat; on the top of the vat is placed the copper goose neck *c*, which is continued into a smaller vat *e* known as the retort; in the latter are placed the low wines resulting from the previous operation. At *f* is shown the rectifier; this consists of an upright cylindrical copper vessel in which are fixed a large
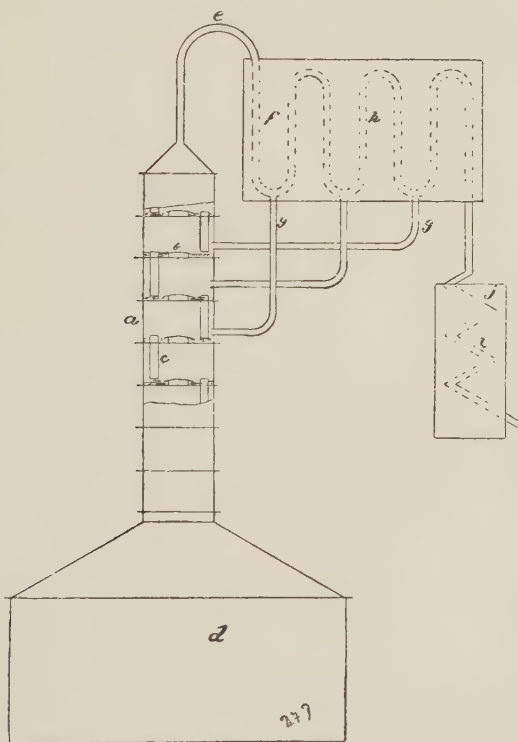
FIG. 279.

number of tubes of small diameter; water is admitted to the rectifier by the pipe *g* and circulates on the outside of these tubes; from the rectifier a pipe passes to the tank *j* in which a supply of cold water circulates, and after passing in a serpentine fashion emerges at *l* and passes on to the spirit receiver. The watery mixture of vapour and alcohol proceeds from the still to the retort where it takes up any alcohol still remaining in the low wines, and passes upwards through the rectifier where a large portion of the water and other bodies of high boiling point condenses and falls back into the retort; the vapour

of alcohol leaves the retort at a temperature of from 180° F. to 190° F. and is condensed in the serpentine in the tank *j*.

Column Still.—In *Fig. 279* is given a semi-diagrammatic view of what is known as the *French column* which is practically identical with *Coupier's* still; the column or dephlegmator *a* is divided into chambers by plates, each of which has a central opening covered by a dome *b*; a small overflow pipe *c* passes from each plate to the next; the vapours from the boiler *d* pass upwards through the central openings through the layer of liquid on each plate, and thence through the overflow pipes back to the boiler; the vapours of high boiling point are condensed in the U pipes *h* in the condenser *f*, passing back to the still by the pipes *g*; a coil *i* is shown in the tank *j* where the spirit is cooled.

Coffey Continuous Still.—The coffey still, *Fig. 280*, consists of two parts, the analyser *A*, and the rectifier *R*; either column is built up of rectangular wooden frames resting one on top of the other and the whole kept in position by a number of vertical stay rods. The analyser is divided into a number of chambers formed by the interposition of copper plates *b b*, perforated with a large number of holes about $\frac{1}{8}$ in. diameter; in each plate is a disc valve *d d* consisting of a disc of copper about 3 in. diameter and opening upwards; from each plate passes down a dip pipe *c c* about 9 in. long and 3 in. diameter; the top of the dip pipe projects about 1 in. above the copper plate and dips into a cup which rests on the next lower plate. The rectifier is divided into chambers by similar diaphragms, save that the five upper chambers are separated from the others by an unperforated copper sheet *n n*, which has a large opening at *p* and a receptacle at *o* from which leads out a pipe *m*; the opening at *p* has a collar 1 in. high; the five upper plates have no valves or perforations, their object being to cause vapour to pass in a serpentine direction.

The method of working is as follows :—Wash is pumped into an overhead tank (not shown) and flows down the pipe *a a*; this pipe is continuous, and emerging at the bottom of the rectifier is carried to the top of the analyser and discharges the wash over the top diaphragm; the wash flows down the analyser in a zig-zag direction passing down the dip pipes, which are placed as shown at alternate ends of the plates; reaching the bottom of the analyser the wash discharges through the pipe *k*. Steam is admitted at a pressure of from 5 to 10 lb. per square inch by the pipe *i i*, and passes upwards through the perforations in the plates; the cups in which the dip pipes stand are always full of wash, and acting as a seal prevent passage of vapour except through the perforations; the dip pipes projecting an inch above the diaphragms always keep this depth of liquid on the plates; in case the vapour is unable to pass
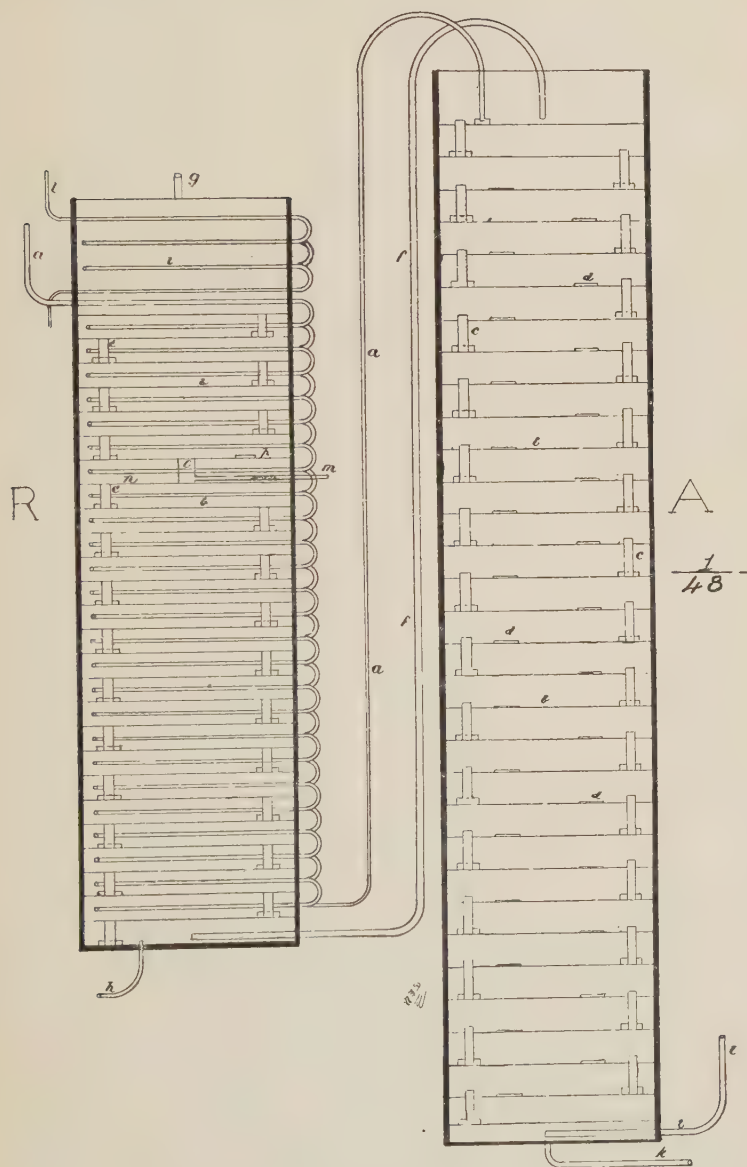
FIG. 280.

quickly enough through the perforations, it can obtain a passage through the valves dd; the steam in its passage through the wash deprives it of its alcohol, and a mixed vapour of alcohol, water and other volatile constituents passes out of the analyser by the pipe ff, and is led into the bottom of the rectifier; as the vapour meets the cold wash in the continuous pipe aa, it is condensed and at the same time heats the wash; the water vapour and bodies of high boiling point, as well as some alcohol, are condensed in the lower part of the still and fall down to the bottom and are continually taken away by the pipe h, called the hot feints pipe. The alcohol in great part condenses in the upper five chambers and falling down on the plate nn, is received in the receptacle o and taken away by the pipe m; this pipe leads to a refrigerator and thence to the spirit store. A pipe g leads from the top of the rectifier and takes away the uncondensed vapour; this pipe too passes through a refrigerator, and the condensed vapours are collected and form the cold feints; ll is a water coil, by means of which the amount of cold feints allowed to be formed can be regulated. The hot feints can either be allowed to mix with the wash or they may be passed through a condenser and pumped to the top of the analyser. The cold feints are collected separately, and when sufficient have accumulated, they are mixed with the wash and redistilled; if pumped directly to the analyser, owing to their low boiling point they volatilize with explosive violence.

The wash leaves the rectifier at a temperature of about 190° F. and is completely exhausted of spirit in its passage down the diaphragms of the analyser, the expelled vapour passing through the pipe ff being at a temperature of about 205° F. to 210° F. The upper coil in the pipe aa is at the temperature of the wash, and the temperature increases regularly on passing down; the strength of spirit condensed in the upper five chambers can be regulated by controlling the temperature. A high temperature causes alcohol to pass off in the cold feint pipes, and at the same time diminishes the condensation of watery vapour so that a weak spirit results; a low temperature makes alcohol condense below the spirit plate, increasing the quantity of hot feints. To obtain the best results the temperature of condensed spirit in the spirit plate should lie between 176° F. and 180° F. The control of the still is effected either by regulating the supply of wash or of steam; valves are fitted, of course, on both the wash pipe and steam pipe. To enable the attendant to know the strength of the spirit at any moment, a small pipe passing through a supplementary refrigerator takes a sample of spirit from the spirit plate, and conducts it to a locked test case; if spirit 45 O.P. is required, three glass bubbles, one which floats in 42 O.P., one in 45 O.P. and one in 48 O.P., are placed in the vessel receiving the spirit; as soon as all three bubbles rise the attendant knows his spirit is too weak, and when two sink that it is too strong. As a further guide thermometers are placed in

various parts of the still; one in the spirit plate, a second at about the twelfth coil of the rectifier, and a third on the pipe carrying wash to the analyser.

To use these stills to greatest advantage they must be worked with as little sudden change as possible; control is effected by regulating either the flow of wash or steam; in forms of stills where the wash is pumped to an overhead tank, opening or shutting a cock or valve (the latter preferably) controls the flow of wash. In other forms where the wash is pumped directly through the coil a cock is fitted on the pipe, convenient to the distiller, and connected to a second pipe leading back to the vessel from which the pump draws. The amount of steam is regulated by a valve; in general it is preferable to control working by the flow of wash.

The spirit should not be run from the spirit plate too rapidly; if the latter be emptied by opening the cock too much, a weak spirit collects and the cock must be closed until the test bubbles show that spirit of the correct strength is forming. The supply of wash and steam must be adjusted to each other; too little steam imperfectly exhausts the wash and an excess results in too much watery vapour passing over, giving a weak spirit. To allow the distiller to see that the wash is properly exhausted, vapour from the lees is collected in a separator, and carried through the supplementary refrigerator to a test glass in which are bubbles floating in water and spirit 98 U.P.; should either of these sink it is certain that the wash is imperfectly exhausted. The advantage of these stills over the common type of vat still lies chiefly in their economy of steam.

Approximate dimensions of a continuous still of the Coffey type working up 1,000 gallons of wash per hour are here given, the letters referring to sketch in *Fig. 280*. Rectifier R, total height 24 ft. × 8 ft. × 3 ft.; analyser A, total height 42 ft. × 8 ft. × 3 ft.; number of chambers in both analyser and rectifier 27; total length of pipe *a a*—contained in analyser—416 ft.; diameter of pipe 2 in.; total surface of pipe 217 square feet; size of dip pipes *c* in rectifier 4 in. × 9 in.; and in analyser 13 in. × 3 in.; diameter of valves *d*, 5 in.; diameter of vapour pipe *f*, 7 in.; diameter of steam pipe *i*, 4 in.; diameter of hot feints pipes *h*, 1½ in.; diameter of spirit pipe, 1¼ in.; diameter of cold feints pipe, 6 in. The still described is one constituted of wood and is of rectangular section; other forms of stills are built throughout of copper and are often of circular section, the wash pipe being worm-shaped instead of straight with U bends as in this case.

The advantage of the Coffey still lies in its economy of steam, the in-coming wash condensing and being heated by the alcohol and water vapour distilled; actually it consumes only about one-third the steam required for a

discontinuous process. Its disadvantages lie in its removing from the product bodies of boiling point remote from that of alcohol and to which the flavour of rum is due; attempts have been made to restrict the term *rum* to the product of discontinuous stills.

Separation of Products of Fermentation.—When using the old forms of vat stills the bodies that have low boiling point pass over in the first runnings, while the fatty acids and higher alcohols having higher boiling points pass over in the last runnings; between these comes over the main body of the distillate; the first and last runnings are collected separately and are called *feints* or *low wines*. In the continuous type of still the bodies of low boiling point are found in the cold feints, the fatty acids in the hot feints; a complete separation is however impossible, and all these bodies are found in greater or less degree in the spirit, dependent on the care exercised by the distiller. The boiling points of the principal constituents of rum are in degrees Fahrenheit:—Alcohol 173°; formic acid 216°; acetic acid 246°; butyric acid 315°; capric acid 380°; ethyl formate 129°; ethyl acetate 168°; ethyl butyrate 241°; ethyl caprate 322°; formaldehyde 70°. It will be seen that ethyl acetate and alcohol have nearly the same boiling point, so that any ethyl acetate present in the fermented wash will be totally recovered with the rum; the other bodies will be present in less quantity as their boiling point is more remote from that of alcohol; the majority of these bodies are, however, volatile in steam and hence are present in the distillate in larger quantity than would be supposed from their boiling point.

Caramel.—Caramel is the name given to the decomposition products obtained on heating sugar or glucose to temperatures in the neighbourhood of 180° C.; a black brittle amorphous highly hygroscopic substance, which reduces Fehling's solution, results. This body is certainly a mixture of various bodies, of the chemistry of which nothing is known. The product when prepared from pure sugar or glucose, and when care is taken to prevent local superheating, is highly soluble in water and to a less degree in spirit; there are present, however, especially when the decomposition is pushed to extremes, caramels which are insoluble in water and soluble in spirit. If these are present in any notable quantity, a perfectly clear 40 O.P. spirit may give a deposit when mixed with water, and to the presence of these caramels is to be attributed one of the causes of faultiness in rum.

Caramel produced by burning sugar is completely soluble in water in the presence of alkalies, and the solution at the same time assumes a much darker colour; but caramels dissolved in spirit are precipitated by alkalies, the solution becoming less coloured; in the presence of alkalies the flavour of the caramel

undergoes a complete change, and at the same time gives off a peculiar odour.

A process which was long kept a trade secret and used, it has been stated, especially for colouring rums, consisted in burning sugar in the presence of alkalies ; the proportions used were 60 parts of sugar and 2 parts of sodium or 1·5 parts of caustic soda. This process is referred to as Asrymusry's; but in view of what has been said above on the action of alkalies on caramel dissolved in spirit, it would hardly promise success. The temperature at which the conversion of sugar into caramel takes place has been stated by different authorities as between 160° C. and 250° C.

When caramel is used for colouring rum, two points have to be considered; the caramel should reduce the strength of the spirit as little as possible, and give to the rum a sugary flavour. To obtain the latter effect the molasses or sugar syrup should not be burned too far, but in this case the amount of caramel required to give the necessary depth of colour so much increases the density of the spirit that there is a large apparent loss.

The usual method of preparing caramel is as under :—Into an iron pot of about 200 gallons' capacity, usually an old iron tayche, are introduced 40 to 50 gallons of molasses, and water added to a density of about 1·25 ; instead of molasses a syrup of sugar and water of the same density is sometimes used. A brick oven is built under the pot, and a brisk fire kept up; the molasses or syrup must be kept in continual motion, preferably by a mechanical stirrer. The sugar solution rapidly darkens, and in from 60 to 90 minutes is quite black. The usual test to show if the caramel is sufficiently burned is to remove a portion on a stick, and after cooling, to break the caramel with the finger; it should be quite brittle. Another test is to drop a globule of the burnt caramel into water, the floating of the globule being an indication that the caramel is sufficiently burned; when either of these tests obtains, the caramel will colour rum reasonably well, but to obtain a low *obscuration* the burning must be continued longer. When the point at which the caramel is sufficiently burned is decided, the fire is drawn and sufficient water added to permit of easy carriage to the rum store.

The higher the temperature at which the caramel is burned, the less is required to produce the necessary depth of colour, and the apparent loss of strength is lower; the after treatment in the rum store has also an effect on the caramel. If the crude colour be repeatedly treated with strong 60 O.P. to 70 O.P. spirit, the colour solution allowed to settle, and the clear colour drawn off, eventually a colour is obtained which gives a barely appreciable obscuration ; this process is too lengthy to carry out in practice, but a colour burnt as described above and treated once, bulk for bulk, with white rum from the still,

will give a fully coloured rum with apparent strength, as shown by the Sikes hydrometer, only from one or two proof degrees less than the actual.

In the West Indies first molasses are generally used to prepare caramel, and one gallon of molasses should afford material sufficient to colour from 50 to 60 gallons of rum.

It is sometimes found that a coloured rum obstinately refuses to settle; in this case the addition of about four ounces of alum per 1000 gallons of spirits will often be found beneficial.

The essential part of the analysis of a caramel is the determination of its colour intensity; this determination is usually made by dissolving a fixed weight of caramel in a definite volume of water or spirit and comparing the colour with a standard prepared under similar conditions, or the colour may be matched in terms of Lovibond's tintometer, which forms a very useful instrument for this purpose. Determinations of the ash and reducing power are also sometimes made; a molasses caramel, of course, carries more ash than a sugar caramel. The copper oxide reducing power varies considerably and generally lies between ·3 and ·6, that of glucose being unit; for highly burnt molasses caramel the writer has found a reducing power of about ·5. Connected inversely with the colour intensity is the obscuration, caramel of high colour intensity giving a low obscuration.

In the preparation of caramels for beers, porters and vinegars, a very well-known trade formula is the addition of salts of ammonia, chiefly the carbonate and chloride, in quantities of one to two pounds per 100 lbs. of sugar or glucose; their addition is said to increase the colour intensity and to modify the harsh bitter taste.

Various patented caramels are on the market; these consist essentially of organic dyes and are not caramels at all; they colour rum with a low obscuration but spoil the flavour and do not keep their colour permanently; their use is not to be recommended. Logwood extract has also been used as a source of colour for rum.

The process described above gives a caramel suited for rums of about 40 O.P.; for rums of proof strength the caramelization must not be carrried so far.

Erlich[33] by heating sugar in vacuo at 200° C. and extracting the product with methyl alcohol and extracting or filtering the residue has obtained a homogeneous body of composition $C_{12}H_{22}O_{11}, 2H_2O$; this body is stated to be the most powerful caramel colour yet made.

Obscuration.—The obscuration of a spirit is the difference between the actual proof strength and the apparent proof strength as determined by an

immersion alcoholometer. Thus spirit showing 40·0 over proof by the alcoholometer, and of actual strength 43·1 over proof is said to have an obscuration of 3·1 ; in some cases, however, the obscuration is expressed on the proof spirit, so that for the example quoted the obscuration is $\frac{3·1}{1·431} = 2·17$ per cent. on proof spirit.

The easiest method of determining the obscuration is as under :—

1. Take the apparent strength by the hydrometer.

2. Evaporate about 200 c.c. of the spirit on a water bath till all the alcohol is removed; take up the residue with water, and make up to the volume of the spirit taken.

3. Take the density of the solution of the residue either by the pycnometer or by a hydrometer graduated to read ·0001. It is absolutely essential that all measurements be made at the temperature at which the instruments are graduated.

Calculation : Let $x =$ specific gravity of the obscured spirit, and $d =$ specific gravity of the residue dissolved in water; then $\frac{x}{d} =$ original gravity of the spirit.

Example : Coloured rum stands 21·0 Sikes at 84° F., indicating an apparent strength of 40·6 O.P.; the specific gravity corresponding to 21 Sikes is ·8512. The density of the residue dissolved in water is 1·0040. Then original gravity of spirit $= \frac{·8512}{1·0040} = ·8478$. The Sikes indication corresponding to a specific gravity of ·8478 is 19·0, indicating a spirit 42·8 O.P. ; hence the obscuration is 42·8 — 40·6 = 2·2.

An older formula for use with this method gives $x - d =$ original gravity of the spirit.

A second method, and one generally used for beers and wines, consists of distilling over the material until all the alcohol has passed over, making the distillate up to the original volume and finding the strength of the distillate by an immersion alcoholometer, which in the absence of solids in solution gives exact results; with strong spirit, such as rum, it is extremely difficult, if not impossible, to prevent loss by evaporation and the first method is preferable.

In the following table are calculated obscurations from the observed density of the residue dissolved in water, the standards adopted for the calcula-

tion being a spirit of strength 40·6 O.P. (=21·0° Sikes) at a temperature of 84° F.; the table is applicable to spirits varying considerably from these adopted standards.

OBSCURATION TABLE.

Density of Dissolved Residue.	Obscuration.	Density of Dissolved Residue.	Obscuration.	Density of Dissolved Residue.	Obscuration.
1·0000	0·0	1·0028	1·5	1·0054	2·9
1·0002	0·2	1·0030	1·7	1·0056	3·0
1·0004	0·3	1·0032	1·8	1·0058	3·1
1·0006	0·4	1·0034	1·9	1·0060	3·1
1·0008	0·5	1·0036	2·0	1·0062	3·2
1·0010	0·6	1·0038	2·1	1·0064	3·3
1·0012	0·7	1·0040	2·2	1·0066	3·4
1·0014	0·8	1·0042	2·3	1·0068	3·5
1·0016	0·9	1·0044	2·4	1·0070	3·6
1·0018	1·0	1·0046	2·5	1·0072	3·7
1·0020	1·1	1·0048	2·6	1·0074	3·7
1·0022	1·2	1·0050	2·7	1·0076	3·8
1·0024	1·3	1·0052	2·8	1·0078	3·9
1·0026	1·4				

Alcoholometry.—Unfortunately in England and her colonies alcohol is measured in 'proof'; a more annoying system could barely have been devised; by proof spirit is meant one which at 62° F. weighs $\frac{12}{13}$ of an equal bulk of water; 40 over proof (O.P.) means that 100 volumes of the spirit contain as much alcohol as 140 volumes of proof; 40 under (U.P.) means that 140 volumes of the spirit contain as much alcohol as 100 volumes of proof; absolute alcohol is 75·25 O.P., so that to convert volumes of proof spirit to alcohol it is necessary to divide by 1·7525 and *vice versa*. Proof spirit contains 49·3 per cent. by weight, 57·06 per cent. by volume of alcohol. In France, and also in Germany, the Gay Lussac scale is used; this is the most rational one and gives directly the percentage of alcohol by volume. The Cartier scale is an empirical one, 43 being absolute alcohol and 22 being proof spirit. The Beck scale is also an empirical one, 43·9 being absolute alcohol and 14·8 being proof spirit. In the U.S.A. the Gendar scale is used; 200 is absolute alcohol, 100 is U.S. proof (*i.e.*, 50 per cent. by volume) and 0 is water.

The bubbles used in distilleries as a guide in the test case are based on the Cartier scale; they are numbered from 16 to 30; bubble 25 corresponds with 25 Cartier, but bubble 26 corresponds to 24 Cartier, &c.

COMPARISON OF THE DIFFERENT ALCOHOL SCALES.

Alcohol per cent. by Volume.	Proof.	Cartier.	Beck.	Gendar.	Bubble.
100	75·25 O.P.	45	44	200	—
95	66·4	40	38	190	—
90	57·6	36·5	34	180	—
85	48·9	33·5	30	170	17
80	40·1	31	27	160	19
75	31·4	29	24	150	21
70	22·7	27	21	140	23
65	13·9	25	18	130	25
60	5·2	23	16	120	27
55	3·6 U.P.	21	14	110	29
50	12·4	20	12	100	30
45	21·1	19	10	90	—
40	29·9	17·5	9	80	—
35	38·7	16·5	7	70	—
30	47·5	15·5	6	60	—
25	56·1	15	5	50	—
20	64·9	14	4	40	—
15	73·7	13·5	3	30	—
10	82·5	13	2	20	—
5	91·2	12	1	10	—
0	0	11	0	0	—

Control of the Distillery.*—In all molasses distilleries with which the writer is acquainted the control is limited to the revenue requirements supplemented occasionally by determinations of the reducing sugars in the wash; a record is in this last case obtained of the amount of sugar required to produce a unit of alcohol. This forms a very imperfect control and a tentative more complete scheme is outlined below.

Fermentation Control.—A composite sample of the wash is collected and in this sample are determined the reducing sugars after inversion expressed as invert sugar; a second sample is fermented with a pure culture of an approved distillery yeast and in the fermented sample are determined the alcohol and the unfermentable sugars; deducting the unfermentable sugars from those originally found gives the amount of fermentable sugars originally present: this quantity should be used in calculating the yield of alcohol per pound of sugar.

The results obtained on the small scale with pure culture should be compared with those found on the commercial scale and the deficiency indicates the loss of alcohol due to imperfections in the process of fermentation.

Distillation Control.—The alcohol in the wash as it enters the still forms the basis of this control; it should be determined in a composite sample, and

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* I purposely do not touch on the biological control; this subject is so specialized that it is out of place here and cannot be satisfactorily treated save in a special work; in the Bibliography I give titles of some books dealing with fermentation; reference should be made to these.—*N. D.*

compared with the amount actually recovered; the balance is to be found in the feints in the lees and in leaks from the still; the alcohol in these residues should also be determined and all expressed as percentages of that originally present; finally an account of the alcohol produced per unit of total and of fermentable sugar should be made out.

Amount of Alcohol obtainable from Molasses.—Fermentation proceeds roughly under the equation

$$C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2$$

Glucose   Alcohol   Carbon dioxide.

Following on this equation 1 lb. of glucose or ·95 lb. of cane sugar could afford ·511 lb. of alcohol and ·489 lb. carbon dioxide; this yield is never obtained in practice even when the distillation losses are disregarded. Peck and Deerr[5] fermented in pure culture a number of molasses with tropical yeasts and found that on an average 90 per cent. of the fermentable sugars were recovered in alcohol, the amount as indicated from the above equation being put equal to 100. In addition, in Hawaiian molasses they found from 4·05 per cent. to 7·32 per cent. of the sugars were unfermentable; previously in Egyptian molasses Pellet had observed 2·40 per cent. of 'glutose' and Deerr had found up to 3 per cent. in Demerara molasses. The total amount of sugars in cane molasses varies from 45 per cent. to 65 per cent. so that it is impossible in the absence of an analysis to state what quantity of alcohol can be obtained from a molasses.

Analyses.—The analyses necessary to a distillery control are indicated briefly below.

Density of Wash.—The methods given for juices in Chapter XXIV. are applicable.

Attenuation.—The attenuation is the difference between the initial and final density, water being put equal to 1000; thus wash initially at 1063 and finally at 1015 is said to have attenuated 48 degrees. For each degree of attenuation it is customary to assume the presence of so much proof spirit; a common allowance is 1 per cent. of proof spirit for every 5 degrees of attenuation. As the result of a series of laboratory fermentations with pure cultures, the writer found 1·17 per cent. of proof spirit for every 5 degrees of attenuation. This method is not meant as an accurate determination of percentage of proof spirit, but as a guide to revenue and customs authorities.

Sugars.—There is no necessity to determine the cane sugars as such; the sugars should be determined after inversion following the methods given in Chapter XXIII.; as the sugars will be mainly dextrose and levulose in approximately equal proportions, it will be best to calculate them as invert sugar.

Alcohol in Wash and Lees.—Take a definite quantity of material, neutralize with caustic soda, and distil until about 90 per cent. of the original volume has been collected; make up with water to original volume and determine the density of the distillate by means of a pycnometer, whence the percentage of alcohol is obtained by reference to the table given below. As lees usually contains very little alcohol it will be well to take a large quantity, say 1000 c.c., distil over 500 c.c., redistil the distillate until 250 c.c. have come over, and finally determine the density of this portion; otherwise the density of the distillate differs so little from unity that a large percentage error may arise.

Alternatively the fractionating still heads of large cooling area, listed by dealers in apparatus, may be used to obtain the alcohol concentrated in a distillate of small volume.

A form of pycnometer which is of great use in the tropics is that due to Boot, where the bottle containing the liquid is enclosed in a second, the space between them being evacuated; liquids may be cooled down to 15° C. and kept in the inner bottle without change of temperature and without the condensation of water on the outside of the bottle.

The table connecting density and percentage of alcohol given below is referred to water at 60° F.; in the tropics materials must be cooled down to near this temperature; in the absence of ice this is best done by dissolving in water a salt such as thiosulphate of soda. Small variations from the standard temperature may be corrected by the use of the expression:

$$D = D' + d \left(\cdot 00014 + \frac{1 - D'}{150} \right)$$

where D is the required density, D' the observed density, d the difference in temperature in centigrade degrees between 15·5° C. (60° F.) and that at which the observation was made.

A table connecting degree Sikes and specific gravity at 84° F. for strong spirits is added as being useful in certain districts.

REFERENCES IN CHAPTER XXVI.

1. *Die Hefepilze.*
2. Perrault. *Le Rhum.*
3. *Bull. Bot. Dept. Jamaica.*, May, Aug., Sept., 1895; Jan., 1896.
4. *Wochenschrift für Brauerei*, 1887, No. 44.
5. *Bull.* 28 *Agric. H.S.P.A.*
6. *Arch.* 1894, 529.

7. *Bull. Assoc.* XXIII., 639.

8. Eng. Patent, 23779 of 1902.

9. Mainly after Klöcker's *Fermentation Organisms.*

10. *Jour. Soc. Chem. Ind.,* 1898, 535.

11. *Proc. Lin. Soc., N.S.W.,* XXVI., 684.

12. *Proc. Lin. Soc., N.S.W.,* XXVI., 589.

13. *Bull.* 9, *Path. H.S.P.A.*

14. *W. I. B.,* VI., 386.

15. *Jour. Am. Chem. Soc. 19,* 238.

16. *S. C.,* 289

17. *I. S. J.,* 126.

18. *The Micro-organism of Faulty Rum,* Oxford, 1897.

19. *S. C.,* 349; *I. S. J.,* 2.

20. *Proc. Lin. Soc., N.S.W.,* XXV., 594; *I. S. J.,* 44 and 45.

21. *Bull.* 21, *Agric. H.S.P.A.*

22. *W. I. B.,* VII., 226.

23. *Louisiana Planter,* XXXIV., 237.

24. From Lafar's *Technical Mycology,* Vol. V.

25. *W. I. B.,* VII., 141.

26. *Timehri.,* 1890, 90.

27. *I. S. J.,* 125, 128, 129.

28. *Arch.* 1905, 379.

29. *British Guiana Official Gazette,* Oct. 19, 1904.

30. *W. I. B.,* VII., 120.

31. *W. I. B.,* VII., 141.

32. *I. S. J.,* 126.

33. *Int. Cong. Applied Chem.,* 1909.

TABLE CONNECTING SPECIFIC GRAVITY AND PERCENTAGE OF ALCOHOL.

Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume	Specific Gravity	Alcohol percent by Volume
1·00000	0·00	0·99854	0·95	0·99716	1·90	0·99579	2·85	0·99445	3·80	0·99315	4·75	0·99189	5·70	0·99065	6·65	0·99947	7·60
0·99992	·05	849	1·00	708	·95	571	·90	438	·85	308	·80	182	·75	059	·70	940	·65
984	·10	842	·05	701	2·00	564	·95	431	·90	301	·85	175	·80	053	·75	934	·70
976	·15	834	·10	694	·05	557	3·00	424	·95	295	·90	169	·85	047	·80	938	·75
968	·20	827	·15	687	·10	550	·05	417	4·00	288	·95	162	·90	040	·85	922	·80
961	·25	819	·20	679	·15	543	·10	410	·05	281	5·00	156	·95	034	·90	916	·85
953	·30	812	·25	672	·20	536	·15	403	·10	274	·05	149	6·00	027	·95	909	·90
945	·35	805	·30	665	·25	529	·20	397	·15	268	·10	143	·05	021	7·00	903	·95
937	·40	797	·35	658	·30	523	·25	390	·20	261	·15	136	·10	015	·05	897	8·00
930	·45	790	·40	651	·35	515	·30	383	·25	255	·20	130	·15	009	·10	891	·05
920	·50	782	·45	643	·40	508	·35	376	·30	248	·25	123	·20	002	·15	885	·10
915	·55	775	·50	636	·45	501	·40	369	·35	241	·30	117	·25	·98996	·20	879	·15
907	·60	768	·55	629	·50	494	·45	363	·40	235	·35	111	·30	990	·25	873	·20
900	·65	760	·60	622	·55	487	·50	356	·45	228	·40	104	·35	984	·30	867	·25
892	·70	753	·65	615	·60	480	·55	349	·50	222	·45	098	·40	978	·35	861	·30
884	·75	745	·70	607	·65	473	·60	342	·55	215	·50	091	·45	971	·40	855	·35
877	·80	738	·75	600	·70	466	·65	335	·60	208	·55	085	·50	965	·45	849	·40
869	·85	731	·80	593	·75	459	·70	329	·65	202	·60	079	·55	959	·50	843	·45
861	·90	723	·85	586	·80	452	·75	322	·70	195	·65	072	·60	953	·55	837	·50

DEGREE SIKES AND SPECIFIC GRAVITY AT 84° F.

	0	·1	·2	·3	·4	·5	·6	·7	·8	·9
17	·8443	·8444	·8446	·8448	·8450	·8452	·8453	·8455	·8457	·8458
18	·8460	·8462	·8464	·8465	·8467	·8469	·8471	·8472	·8474	·8476
19	·8478	·8479	·8481	·8483	·8485	·8487	·8488	·8490	·8492	·8493
20	·8495	·8497	·8498	·8500	·8502	·8503	·8505	·8507	·8509	·8510
21	·8512	·8514	·8516	·8518	·8519	·8521	·8523	·8524	·8526	·8528
22	·8530	·8531	·8533	·8535	·8537	·8538	·8540	·8542	·8544	·8546

APPENDIX.

TABLES

AND

ADDITIONAL NOTES RELATING TO CERTAIN PORTIONS
OF THE TEXT.

PROPERTIES OF SATURATED STEAM.

(After Peabody.)

ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
32	0·0886	0·0	1071·7	3308
33	0·0923	1·0	1071·2	3179
34	0·0960	2·0	1070·7	3062
35	0·0999	3·0	1070·2	2950
36	0·1040	4·0	1069·7	2842
37	0·1082	5·0	1069·2	2737
38	0·1126	6·1	1068·7	2634
39	0·1171	7·1	1068·2	2538
40	0·1217	8·1	1067·6	2446
41	0·1265	9·1	1067·1	2358
42	0·1315	10·1	1066·6	2272
43	0·1367	11·1	1066·0	2190
44	0·1421	12·1	1065·5	2110
45	0·1476	13·1	1065·0	2035
46	0·1533	14·1	1064·4	1963
47	0·1591	15·1	1063·9	1894
48	0·1652	16·1	1063·4	1828
49	0·1715	17·1	1062·8	1764
50	0·1780	18·1	1062·3	1703
51	0·1848	19·1	1061·8	1643
52	0·1918	20·1	1061·3	1586
53	0·1990	21·1	1060·7	1531
54	0·2064	22·1	1060·2	1479
55	0·2140	23·1	1059·7	1429
56	0·2219	24·1	1059·1	1381
57	0·2301	25·1	1058·6	1335
58	0·2385	26·1	1058·1	1291
59	0·2471	27·1	1057·6	1248
60	0·2561	28·1	1057·0	1207
61	0·2654	29·1	1056·5	1167
62	0·2750	30·1	1056·0	1128
63	0·2848	31·1	1055·5	1091
64	0·2949	32·1	1055·0	1056
65	0·3054	33·1	1054·4	1021
66	0·3161	34·1	1053·9	988
67	0·3272	35·1	1053·4	956
68	0·3386	36·1	1052·8	925

PROPERTIES OF SATURATED STEAM.—*Continued.*

ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume. cubic feet per pound.
69	0·3505	37·1	1052·3	896
70	0·3627	38·1	1051·8	868
71	0·3752	39·1	1051·2	840
72	0·3879	40·1	1050·7	813
73	0·4012	41·1	1050·2	788
74	0·4149	42·1	1049·7	763
75	0·4289	43·1	1049·2	739
76	0·4434	44·1	1048·7	717
77	0·4582	45·1	1048·1	695
78	0·4736	46·1	1047·6	674
79	0·4894	47·1	1047·1	654
80	0·5056	48·1	1046·5	634
81	0·5223	49·1	1046·0	615
82	0·5395	50·1	1045·4	596
83	0·5572	51·1	1044·9	578
84	0·5754	52·1	1044·4	561
85	0·5942	53·1	1043·9	544
86	0·6134	54·1	1043·3	528
87	0·6332	55·1	1042·8	513
88	0·6535	56·1	1042·3	498·0
89	0·6745	57·1	1041·7	483·4
90	0·6960	58·1	1041·2	469·2
91	0·7181	59·1	1040·6	455·4
92	0·7408	60·1	1040·1	442·0
93	0·7642	61·1	1039·5	429·1
94	0·7882	62·1	1039·0	416·7
95	0·8128	63·1	1038·5	404·8
96	0·8381	64·1	1037·9	393·3
97	0·8640	65·0	1037·4	382·1
98	0·8907	66·0	1036·8	371·3
99	0·9180	67·0	1036·3	360·9
100	0·9461	68·0	1035·7	350·8
101	0·9751	69·0	1035·1	341·1
102	1·0047	70·0	1034·6	331·6
103	1·0351	71·0	1034·0	322·4
104	1·0663	72·0	1033·5	313·5
105	1·098	73·0	1032·9	304·8
106	1·131	74·0	1032·4	296·4
107	1·165	75·0	1031·8	288·2
108	1·200	76·0	1031·2	280·2
109	1·235	77·0	1030·7	272·6
110	1·271	78·0	1030·1	265·2

Properties of Saturated Steam.—*Continued.*

ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
111	1·308	79·0	1029·6	258·0
112	1·347	80·0	1029·0	251·1
113	1·386	81·0	1028·4	244·4
114	1·426	82·0	1027·8	238·0
115	1·467	83·0	1027·2	231·8
116	1·509	84·0	1026·7	225·7
117	1·552	85·0	1026·1	219·8
118	1·597	86·0	1025·5	214·0
119	1·642	87·0	1025·0	208·4
120	1·689	88·0	1024·4	203·0
121	1·737	89·0	1023·8	197·8
122	1·785	90·0	1023·2	192·7
123	1·835	91·0	1022·7	187·7
124	1·886	92·0	1022·1	182·9
125	1·938	93·0	1021·5	178·3
126	1·992	94·0	1021·0	173·8
127	2·047	95·0	1020·4	169·4
128	2·103	96·0	1019·8	165·2
129	2·161	97·0	1019·3	161·1
130	2·220	98·0	1018·7	157·1
131	2·280	99·0	1018·1	153·2
132	2·441	100·0	1017·6	149·5
133	2·403	101·0	1017·0	145·8
134	2·467	102·0	1016·5	142·2
135	2·533	103·0	1015·9	138·8
136	2·600	104·0	1015·4	135·4
137	2·669	105·0	1014·8	132·1
138	2·740	106·0	1014·2	128·9
139	2·812	107·0	1013·6	125·8
140	2·885	108·0	1013·1	122·8
141	2·960	109·0	1012·5	119·9
142	3·037	110·0	1011·9	117·1
143	3·116	111·0	1011·4	114·3
144	3·196	112·0	1010·8	111·6
145	3·278	113·0	1010·2	109·0
146	3·361	114·0	1009·6	106·5
147	3·447	115·0	1009·0	104·0
148	3·535	116·0	1008·4	101·6
149	3·624	117·0	1007·8	99·2
150	3·715	118·0	1007·2	96·9
151	3·808	119·0	1006·7	94·7
152	3·903	120·0	1006·1	92·5

PROPERTIES OF SATURATED STEAM.—*Continued.*
ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
153	4·000	121·0	1005·5	90·4
154	4·099	122·0	1004·9	88·4
155	4·200	123·0	1004·3	86·4
156	4·303	124·0	1003·7	84·5
157	4·409	125·0	1003·1	82·6
158	4·517	126·0	1002·5	80·7
159	4·626	127·0	1002·0	78·9
160	4·738	128·0	1001·4	77·2
161	4·852	129·0	1000·8	75·4
162	4·969	130·0	1000·2	73·7
163	5·088	131·0	999·6	72·1
164	5·210	132·0	999·0	70·6
165	5·334	133·0	998·4	69·1
166	5·460	134·0	997·9	67·7
167	5·589	135·0	997·3	66·2
168	5·720	136·0	996·7	64·8
169	5·853	137·0	996·1	63·4
170	5·990	138·0	995·5	62·0
171	6·129	139·0	994·9	60·6
172	6·270	140·0	994·3	59·3
173	6·415	141·0	993·7	58·1
174	6·563	142·0	993·1	56·9
175	6·714	143·0	992·5	55·7
176	6·868	144·0	991·9	54·5
177	7·025	145·0	991·3	53·4
178	7·185	146·0	990·7	52·3
179	7·346	147·0	990·1	52·2
180	7·510	148·0	989·5	50·2
181	7·678	149·0	988·9	49·13
182	7·849	150·1	988·3	48·11
183	8·024	151·1	987·7	47·12
184	8·202	152·1	987·1	46·17
185	8·383	153·1	986·5	45·23
186	8·568	154·1	985·9	44·33
187	8·756	155·1	985·3	43·45
188	8·947	156·1	984·7	42·59
189	9·141	157·1	984·0	41·75
190	9·339	158·1	983·4	40·92
191	9·541	159·1	982·8	40·11
192	9·746	160·1	982·2	39·31
193	9·955	161·1	981·5	38·53
194	10·168	162·1	980·9	37·77

Properties of Saturated Steam.—*Continued.*

ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
195	10·385	163·1	980·3	37·03
196	10·605	164·1	979·7	36·31
197	10·830	165·1	979·1	35·61
198	11·059	166·2	978·4	34·93
199	11·291	167·2	977·8	34·27
200	11·528	168·2	977·2	33·62
201	11·768	169·2	976·6	32·99
202	12·013	170·2	976·0	32·37
203	12·261	171·2	975·4	31·75
204	12·514	172·2	974·7	31·15
205	12·771	173·2	974·1	30·56
206	13·033	174·2	973·5	29·98
207	13·299	175·2	972·8	29·41
208	13·570	176·2	972·2	28·86
209	13·845	177·2	971·6	28·32
210	14·125	178·3	970·9	27·80
211	14·409	179·3	970·3	27·29
212	14·698	180·3	969·7	26·78
213	14·992	181·3	969·1	26·29
214	15·291	182·3	968·5	25·81
215	15·595	183·3	967·8	25·34
216	15·903	184·3	967·2	24·88
217	16·217	185·3	966·5	24·43
218	16·536	186·3	965·9	23·99
219	16·859	187·4	965·2	23·56
220	17·188	188·4	964·6	23·14
221	17·523	189·4	964·0	22·75
222	17·863	190·4	963·3	22·33
223	18·208	191·4	962·7	21·93
224	18·558	192·4	962·0	21·54
225	18·914	193·4	961·4	21·16
226	19·275	194·4	960·7	20·78
227	19·643	195·4	960·1	20·42
228	20·02	196·5	959·4	20·07
229	20·40	197·5	958·7	19·72
230	20·78	198·5	958·1	19·37
231	21·17	199·5	957·4	19·04
232	21·57	200·5	956·8	18·71
233	21·97	201·5	956·1	18·39
234	22·38	202·5	955·4	18·08
235	22·79	203·6	954·8	17·77
236	23·21	204·6	954·1	17·46

PROPERTIES OF SATURATED STEAM.—*Continued.*
ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
237	23·64	205·6	953·4	17·16
238	24·08	206·6	952·8	16·87
239	24·52	207·6	952·1	16·59
240	24·97	208·6	951·4	16·31
241	25·42	209·6	950·8	16·04
242	25·88	210·7	950·1	15·77
243	26·35	211·7	949·4	15·51
244	26·83	212·7	948·7	15·26
245	27·31	213·7	948·1	15·01
246	27·80	214·7	947·4	14·77
247	28·29	215·7	946·7	14·52
248	28·79	216·7	946·0	14·28
249	29·30	217·7	945·4	14·05
250	29·82	218·8	944·7	13·82
251	30·35	219·8	944·0	13·59
252	30·88	220·8	943·3	13·37
253	31·42	221·8	942·6	13·16
254	31·97	222·8	941·9	12·94
255	32·53	223·8	941·2	12·73
256	33·09	224·9	940·5	12·53
257	33·66	225·9	939·8	12·33
258	34·24	226·9	939·1	12·13
259	34·83	227·9	938·4	11·94
260	35·42	229·0	937·8	11·75
261	36·02	230·0	937·1	11·57
262	36·64	231·0	936·4	11·39
263	37·26	232·0	935·7	11·21
264	37·89	233·0	935·0	11·04
265	38·53	234·0	934·3	10·87
266	39·17	235·0	933·6	10·70
267	39·83	236·1	932·9	10·53
268	40·49	237·1	932·1	10·37
269	41·16	238·1	931·4	10·21
270	41·84	239·1	930·7	10·05
271	42·54	240·2	930·0	9·901
272	43·24	241·2	929·3	9·749
273	43·95	242·2	928·6	9·599
274	44·67	243·2	927·9	9·453
275	45·39	244·2	927·2	9·309
275·8	46·	245·1	926·6	9·195
277·16	47·	246·4	925·6	9·012
278·47	48·	247·8	924·7	8·838

PROPERTIES OF SATURATED STEAM.—*Continued.*

ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
279·76	49·	249·1	923·8	8·670
281·03	50·	250·4	922·8	8·507
282·28	51·	251·7	921·9	8·350
283·52	52·	253·0	921·0	8·198
284·74	53·	254·2	920·1	8·052
285·93	54·	255·4	919·3	7·912
287·09	55·	256·6	918·4	7·778
288·25	56·	257·8	917·6	7·647
289·40	57·	259·0	916·7	7·519
290·53	58·	260·1	915·9	7·397
291·64	59·	261·3	915·1	7·280
292·74	60·	262·4	914·3	7·166
293·82	61·	263·5	913·5	7·055
294·88	62·	264·6	912·7	6·949
295·93	63·	265·7	911·9	6·846
296·97	64·	266·7	911·1	6·745
298·00	65·	267·8	910·4	6·647
299·02	66·	268·8	909·6	6·552
300·02	67·	269·8	908·9	6·460
301·01	68·	270·9	908·1	6·370
301·99	69·	271·9	907·4	6·283
302·96	70·	272·9	906·6	6·199
303·91	71·	273·8	905·9	6·117
304·86	72·	274·8	905·2	6 036
305·79	73·	275·8	904·5	5·958
306·72	74·	276·7	903·8	5·882
307·64	75·	277·7	903·1	5·807
308·54	76·	278·6	902·4	5·735
309·44	77·	279·5	901·8	5·665
310·33	78·	280·4	901·1	5·597
311·21	79·	281·3	900·4	5·530
312·08	80·	282·2	899·8	5·466
312·94	81·	283·1	899·1	5·403
313·79	82·	283·9	898·5	5·342
314·63	83·	284·8	897·8	5·281
315·47	84·	285·7	897·2	5·220
316·30	85·	286·5	896·6	5·161
317·12	86·	287·4	895·9	5·104
317·93	87·	288·2	895·3	5·048
318·73	88·	289·0	894·7	4·993
319·53	89·	289·9	894·1	4·939
320·32	90·	290·7	893·5	4·886

PROPERTIES OF SATURATED STEAM.—*Continued*.
ENGLISH UNITS.

Temperature degrees Fahrenheit.	Pressure lbs. per square inch.	Heat of the Liquid.	Heat of Vaporization.	Specific Volume cubic feet per pound.
321·10	91·	291·5	892·9	4·835
321·88	92·	292·3	892·3	4·785
322·65	93·	293·1	891·7	4·736
323·41	94·	293·9	891·1	4·689
324·16	95·	294·6	890·5	4·644
324·91	96·	295·4	889·9	4·599
325·66	97·	296·2	889·3	4·556
326·40	98·	296·9	888·7	4·514
327·13	99·	297·7	888·2	4·473
327·86	100·	298·5	887·6	4·432
328·58	101·	299·2	887·0	4·391
329·30	102·	299·9	886·5	4·351
330·01	103·	300·6	885·9	4·311
330·72	104·	301·4	885·3	4·272
331·42	105·	302·1	884·8	4·233
332·11	106·	302·8	884·3	4·195
332·79	107·	303·5	883·7	4·157
333·48	108·	304·2	883·2	4·120
334·16	109·	304·9	882·6	4·083
334·83	110·	305·6	882·1	4·047
335·50	111·	306·3	881·6	4·011
336·17	112·	307·0	881·0	3·976
336·83	113·	307·7	880·5	3·943
337·48	114·	308·3	880·0	3·909
338·14	115·	309·0	879·5	3·876
338·78	116·	309·7	879·0	3·844
339·42	117·	310·3	878·5	3·812
340·06	118·	311·0	878·0	3·781
340·69	119·	311·7	877·4	3·752
341·31	120·	312·3	876·9	3·723
341·94	121·	312·9	876·4	3·694
342·56	122·	313·6	875·9	3·665
343·18	123·	314·2	875·4	3·637
343·79	124·	314·8	875·0	3·609
344·39	125·	315·5	874·5	3·581
345·00	126·	316·1	874·0	3·554
345·60	127·	316·7	873·5	3·527
346·20	128·	317·3	873·0	3·501
346·79	129·	317·9	872·6	3·476
347·38	130·	318·6	872·1	3·451

CORRESPONDENCE BETWEEN BRIX AND SPECIFIC GRAVITY. $\dfrac{17\cdot5^\circ\mathrm{C.}}{17\cdot5^\circ\mathrm{C.}}$

Degree Brix.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
0	1·00000	1·00038	1·00077	1·00116	1·00155	1·00193	1·00232	1·00271	1·00310	1·00349
1	1·00388	1·00427	1·00466	1·00505	1·00544	1·00583	1·00622	1·00662	1·00701	1·00740
2	1·00779	1·00818	1·00858	1·00897	1·00936	1·00976	1·01015	1·01055	1·01094	1·01134
3	1·01173	1·01213	1·01252	1·01292	1·01332	1·01371	1·01411	1·01451	1·01491	1·01531
4	1·01570	1·01610	1·01650	1·01690	1·01730	1·01770	1·01810	1·01850	1·01890	1·01930
5	1·01970	1·02010	1·02051	1·02091	1·02131	1·02171	1·02211	1·02252	1·02292	1·02333
6	1·02373	1·02413	1·02454	1·02494	1·02535	1·02575	1·02616	1·02657	1·02697	1·02738
7	1·02779	1·02819	1·02860	1·02901	1·02942	1·02983	1·03024	1·03064	1·03105	1·03146
8	1·03187	1·03228	1·03270	1·03311	1·03352	1·03393	1·03434	1·03475	1·03517	1·03558
9	1·03599	1·03640	1·03682	1·03723	1·03765	1·03806	1·03848	1·03889	1·03931	1·03972
10	1·04014	1·04055	1·04097	1·04139	1·04180	1·04222	1·04264	1·04306	1·04348	1·04390
11	1·04431	1·04473	1·04515	1·04557	1·04599	1·04641	1·04683	1·04726	1·04768	1·04810
12	1·04852	1·04894	1·04937	1·04979	1·05021	1·05064	1·05106	1·05149	1·05191	1·05233
13	1·05276	1·05318	1·05361	1·05404	1·05446	1·05489	1·05532	1·05574	1·05617	1·05660
14	1.05703	1·05746	1·05789	1·05831	1·05874	1·05917	1·05960	1·06003	1·06047	1·06090
15	1·06133	1·06176	1·06219	1·06262	1·06306	1·06349	1·06392	1·06436	1·06479	1·06522
16	1·06566	1·06609	1·06653	1·06696	1·06740	1·06783	1·06827	1·06871	1·06914	1·06958
17	1·07002	1·07046	1·07090	1·07133	1·07177	1·07221	1·07265	1·07309	1·07358	1·07397
18	1·07441	1·07485	1·07530	1·07574	1·07618	1·07662	1·07706	1·07751	1·07795	1·07839
19	1·07884	1·07928	1·07973	1·08017	1·08062	1·08106	1·08151	1·08196	1·08240	1·08285
20	1·08329	1·08374	1·08419	1·08464	1·08509	1 08553	1·08599	1·08643	1·08688	1·08732
21	1·08778	1·08824	1·08869	1·08914	1·08959	1·09004	1·09049	1·09095	1·09140	1·09185
22	1·09231	1·09276	1·09321	1·09367	1·09412	1·09458	1·09503	1·09549	1·09595	1·09640
23	1·09686	1·09732	1·09777	1·09823	1·09869	1·09915	1·09961	1·10007	1·10053	1·10099
24	1·10145	1·10191	1·10237	1·10283	1·10329	1·10375	1·10421	1·10468	1·10514	1·10566
25	1·10607	1·10653	1·10700	1·10746	1·10793	1·10839	1·10886	1·10932	1·10979	1·11026
26	1·11072	1·11119	1·11166	1·11213	1·11259	1·11306	1·11353	1·11400	1·11447	1·11494
27	1·11541	1·11588	1·11635	1·11682	1·11729	1·11776	1·11824	1·11871	1·11918	1·11965
28	1·12013	1·12060	1·12107	1·12155	1·12202	1·12250	1·12297	1·12345	1·12393	1·12440
29	1·12488	1·12536	1·12583	1·12631	1·12679	1·12727	1·12775	1·12823	1·12871	1·12919
30	1·12967	1·13015	1·13063	1·13111	1·13159	1·13207	1·13255	1·13304	1·13352	1·13400
31	1·13449	1·13497	1·13545	1·13594	1·13642	1·13691	1·13740	1·13788	1·13837	1·13885
32	1·13934	1·13983	1·14032	1·14081	1·14129	1·14178	1·14227	1·14276	1·14325	1·14374
33	1·14423	1·14472	1·14521	1·14570	1·14620	1·14669	1·14718	1·14767	1·14817	1·14866
34	1·14915	1·14965	1·15014	1·15064	1·15113	1·15163	1·15213	1·15262	1·15312	1·15362
35	1·15411	1·15461	1·15511	1·15561	1·15611	1·15661	1·15710	1·15760	1·15810	1·15861
36	1·15911	1·15961	1·16011	1·16061	1·16111	1·16162	1·16212	1·16262	1·16313	1·16363
37	1·16413	1·16464	1·16514	1·16565	1·16616	1·16666	1·16717	1·16768	1·16818	1·16869
38	1·16920	2·16971	1·17022	1·17072	1·17123	1·17174	1·17225	1·17276	1·17327	1·17379

CORRESPONDENCE BETWEEN BRIX AND SPECIFIC GRAVITY. $\frac{17\cdot5\,^{\circ}\text{C.}}{17\cdot5\,^{\circ}\text{C.}}$ —*Continued.*

Degree Brix.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
39	1·17430	1·17481	1·17532	1·17583	1·17635	1·17686	1·17737	1·17789	1·17840	1·17892
40	1·17943	1·17995	1·18046	1·18098	1·18150	1·18201	1·18253	1·18305	1·08357	1·18408
41	1·18460	1·18512	1·18564	1·18616	1·18668	1·18720	1·18772	1·18824	1·18877	1·18929
42	1·18981	1·19033	1·19086	1·19138	1·19190	1·19243	1·19295	1·19348	1·19400	1·19453
43	1·19505	1·19558	1·19611	1·19663	1·19716	1·19769	1·19822	1·19875	1·19927	1·19980
44	1·20033	1·20086	1·20139	1·20192	1·20245	1·20299	1·20352	1·20405	1·20458	1·20512
45	1·20565	1·20618	1·20672	1·20725	1·20779	1·20832	1·20886	1·20939	1·20993	1·21046
46	1·21100	1·21154	1·21208	1·21261	1·21315	1·21369	1·21423	1·21477	1·21531	1·21585
47	1·21639	1·21693	1·21747	1·21802	1·21856	1·21910	1·21964	1·22019	1·22073	1·22127
48	1·22182	1·22236	1·22291	1·25345	1·22400	1·22455	1·22509	1·22564	1·22619	1·22673
49	1·22728	1·22783	1·22838	1·22893	1·22948	1·23003	1·23058	1·23113	1·23168	1·23223
50	1·23278	1·23334	1·23389	1·23444	1·23499	1·23555	1·23610	1·23666	1·23721	1·23777
51	1·23832	1·23888	1·23943	1·23999	1·24055	1·24111	1·24166	1·24222	1·24278	1·24334
52	1·24390	1·24446	1·24502	1·24558	1·24614.	1·24670	1·24726	1·24782	1·24839	1·24895
53	1·24951	1·25008	1·25064	1·25120	1·25177	1·25233	1·25290	1·25347	1·25403	1·25460
54	1·25517	1·25573	1·25630	1·25687	1·25744	1·25801	1·25857	1·25914	1·25971	1·26028
55	1·26086	1·26143	1·26200	1·26257	1·26314	1·26372	1·26429	1·26486	1·26544	1·26601
56	1·26658	1·26716	·26773	1·26831	1·26889	1·26946	1·27004	1·27062	1·27120	1·27177
57	1·27235	1·27293	1·27351	1·27409	1·27467	1·27525	1·27583	1·27641	1·27669	1·27758
58	1·27816	1·27874	1·27932	1·27991	1·28049	1·28107	1·28166	1·28224	1·28283	1·28342
59	1·28400	1·28459	1·28518	1·28576	1·28635	1·28694	1·28753	1·28812	1·28871	1·28930
60	1·28989	1·29048	1·29107	1·29166	1·29225	1·29284	1·29343	1·29403	1·29462	1·29521
61	1·29581	1·29640	1·29700	1·29759	1·29819	1·29878	1·29938	1·29998	1·30057	1·30117
62	1·30177	1·30237	1·30297	1·30356	1·30416	1·30476	1·30536	1·30596	1·30657	1·30717
63	1·30777	1·30837	1·30897	1·30958	1·31018	1·31078	1·31139	1·31199	1·31260	1·31320
64	1·31381	1·31442	1·31502	1·31563	1·31624	1·31684	1 31745	1·31806	1·31867	1·31928
65	1·31989	1·32050	1·32111	1·32172	1·32233	1·32294	1·32355	1·32417	1·32478	1·32539
66	1·32601	1·32662	1·32724	1·32785	1·32847	1·32908	1·32970	1·33031	1·33093	1·33155
67	1·33217	1·33278	1·33340	1·33402	1·33464	1·33526	1·33588	1·33650	1·33712	1·33774
68	1·33836	1·33899	1·33961	1·34023	1·34085	1·34148	1·34210	1·34273	1·34335	1·34398
69	1·34460	1·34523	1·34585	1·34648	1·34711	1·34774	1·34836	1·34899	1·34962	1·35025
70	1·35088	1·35151	1·35214	1·35277	1·35340	1·35403	1·35466	1·35530	1·35593	1·35656
71	1·35720	1·35783	1·35847	1·35910	1·35974	1·36037	1·36101	1·36164	1·36228	1·36292
72	1·36355	1·36419	1·36483	1·36547	1·36611	1·36675	1·37739	1·36803	1·36867	1·36931
73	1·36995	1·37059	1·37124	1·37188	1·37252	1·37317	1·37381	1·37446	1·37510	1·37575
74	1·37639	1·37704	1·37768	1·37833	1·37898	1·37962	1·38027	1·38092	1·38157	1·38222
75	1·38287	1·38352	1·38417	1·38482	1·38547	1·38612	1·38677	1·38743	1·38808	1·38873
76	1·38239	1·39004	1·39070	1·39135	1·39201	1·39266	1·39332	1·39397	1·39463	1·39529
77	1·39595	1·39660	1·39726	1·39792	1·39858	1·39924	1·39990	1·40056	1·40122	1·40188
78	1·40254	1·40321	1·40387	1·40453	1·40520	1·40586	1·40652	1·40719	1·40785	1·40852
79	1·40918	1·40985	1·41052	1·41118	1·41185	1·41252	1·41318	1·41385	1·41452	1·41519
80	1·41586	1·41653	1·41720	1·41787	1·41854	1,41921	1·41989	1·42056	1·42123	1·42190
81	1·42258	1·42325	1·42393	1·42460	1·42528	1·42595	1·42663	1·42731	1·42798	1·42866

CORRESPONDENCE BETWEEN BRIX AND SPECIFIC GRAVITY. $\frac{17\cdot5\,^{\circ}\text{C.}}{17\cdot5\,^{\circ}\text{C.}}$ —*Continued.*

Degree Brix.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
82	1·42934	1·43002	1·43070	1·43137	1·43205	1·43273	1·43341	1·43409	1·43478	1·43546
83	1·43614	1·43682	1·43750	1·43819	1·43887	1·43955	1·44024	1·44092	1·44161	1·44229
84	1·44298	1·44367	1·44435	1·44504	1·44573	1·44641	1·44710	1·44779	1·44841	1·44917
85	1·44986	1·45055	1·45124	1·45193	1·45262	1·45331	1·45401	1·45470	1·45539	1·45609
86	1·45678	1·45748	1·45817	1·45887	1·45956	1·46026	1·46095	1·46165	1·46235	1·46304
87	1·46374	1·46444	1·46514	1·46584	1·46654	1·46724	1·46794	1·46864	1·46934	1·47004
88	1·47074	1·47145	1·47215	1·47285	1·47356	1·47426	1·47496	1·47567	1·47637	1·57708
89	1·47778	1·47849	1·47920	1·47991	1·48061	1·48132	1·48203	1·48274	1·48345	1·48416
90	1·48486	1·48558	1·48629	1·48700	1·48771	1·48842	1·48813	1·48985	1·49056	1·49127
91	1·49199	1·49270	1·49342	1·49413	1·49485	1·49556	1·49628	1·49700	1·49771	1·49843
92	1·49915	1·49987	1·50058	1·50130	1·50202	1·50274	1·50346	1·50419	1·50491	1·50563
93	1·50635	1·50707	1·50779	1·50852	1·50924	1·50996	1·51069	1·51141	1·51214	1·51286
94	1·51359	1·51431	1·51504	1·51577	1·51640	1·51722	1·51795	1·51868	1·51941	1·52014
95	1·52087	1·52159	1·52232	1·52304	1·52376	1·52449	1·52521	1·52593	1·52665	1·52738
96	1·52810	1·52884	1·52958	1·53032	1·53106	1·53180	1·53254	1·53328	1·53402	1·53476
97	1·53550	1·53624	1·53698	1·53772	1·53846	1·53920	1·53994	1·54068	1·54142	1·54216
98	1·54290	1·54365	1·54440	1·54515	1·54590	1·54665	1·54740	1·54815	1·54890	1·54965
99	1·55040	1·55115	1·55189	1·55264	1·55338	1·55413	1·55487	1·55562	1·55636	1·55711
100	1·55785									

CORRESPONDENCE BETWEEN BRIX AND SPECIFIC GRAVITY. $\dfrac{20°\text{C.}}{4°\text{C.}}$

Degree Brix.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
0	·99823	·99862	·99901	·99940	·99979	1·00017	1·00056	1·00095	1·00134	1·00173
1	1·00212	1·00251	1·00290	1·00329	1·00367	1·00406	1·00445	1 00484	1·00523	1·00562
2	1·00601	1·00640	1·00680	1·00719	1·00758	1·00797	1·00836	1·00875	1·00915	1·00954
3	1·00993	1·01033	1.01072	1·01111	1·01151	1·01190	1·01230	1·01269	1·01309	1·01348
4	1·01388	1·01428	1·01467	1·01507	1·01547	1·01586	1·01626	1·01666	1·01706	1·01746
5	1·01785	1·01825	1·01865	1·01905	1·01945	1·01985	1·02025	1·02065	1·02105	1·02145
6	1·02185	1·02226	1·02266	1·02306	1·02346	1·02387	1·02427	1·02467	1·02508	1·09548
7	1·02588	1·02629	1·02669	1·02710	1·02750	1·02791	1·02832	1·02872	1·02913	1·02953
8	1·02994	1·03035	1·03076	1·03116	1·03157	1·03198	1·03239	1·03280	1·03321	1·03362
9	1 03403	1·03444	1·03485	1·03526	1·03567	1·03608	1·03649	1·03691	1·03732	1·03773
10	1·03814	1·03856	1·03897	1·03938	1·03980	1·04021	1·04063	1·04104	1·04146	1·04187
11	1·04229	1·04270	1·04312	1·04354	1·04395	1·04437	1·04479	1·04521	1·04562	1·04604
12	1·04646	1·04688	1·04730	1·04772	1·04814	1·04856	1·04898	1·04940	1·04982	1·05024
13	1·05066	1·05109	1·05151	1·05193	1·05236	1·05278	1·05320	1·05363	1·05405	1·05447
14	1·05490	1·05532	1·05575	1·05618	1·05660	1·05703	1·05745	1·05788	1·05831	1·05874
15	1·05916	1·05959	1·06002	1·06045	1·06088	1·06121	1·06174	1·06217	1·06260	1·06303
16	1·06346	1·06389	1·06432	1·06476	1·06519	1·06562	1·06605	1·06649	1·06692	1·06735
17	1·06779	1·06822	1·06866	1·06909	1·06953	1·06996	1·07040	1·07084	1·07127	1·07171
18	1·07215	1·07256	1·07302	1·07346	1·07390	1·07434	1·07478	1·07522	1·07566	1·07610
19	1·07654	1·07698	1·07742	1·07786	1·07830	1·07874	1·07919	1·07963	1·08007	1·08052
20	1·08096	1·08140	1·08185	1·08229	1·08274	1·08318	1·08363	1·08407	1·08452	1·08497
21	1·08541	1·08586	1·08631	1·08676	1·08720	1·08765	1·08810	1·08855	1·08900	1·08945
22	1·08990	1·09035	1·09080	1·09125	1·09170	1·09215	1·09261	1·09306	1·09351	1·09397
23	1·09442	1·09487	1·09533	1·09578	1·09624	1·09669	1·09715	1·09760	1·09806	1·09851
24	1·09897	1·09943	1·09989	1·10034	1·10080	1·10126	1·10172	1·10218	1·10264	1·10310
25	1·10356	1·10402	1·10448	1·10494	1·10540	1·10586	1·10632	1·10679	1·10725	1·10771
26	1·10817	1·10884	1·10910	1·10957	1·11003	1·11050	1·11096	1·11143	1·11189	1·11236
27	1·11283	1·11329	1·11386	1·11423	1·11470	1·11517	1·11563	1·11610	1·11657	1·11714
28	1·11751	1·11798	1·11845	1·11892	1·11939	1·11987	1·12034	1·12081	1·12128	1·12176
29	1·12223	1·12270	1·12318	1·12365	1·12413	1·12460	1·12508	1 12555	1·12603	1·12651
30	1·12698	1·12746	1·12794	1·12842	1·12890	1·12937	1·12985	1·13033	1·13081	1·13129
31	1·13177	1·13225	1·13273	1·13322	1·13370	1·13418	1·13466	1·13515	1·13563	1·13611
32	1·13660	1·13708	1·13756	1·13805	1·13853	1·13902	1·13951	1·13999	1·14048	1·14097
33	1·14145	1·14194	1·14243	1·14292	1·14340	1·14389	1·14438	1·14487	1·14536	1·14585
34	1·14634	1·14684	1·14733	1·14782	1·14831	1·14880	1·14930	1·14979	1·15029	1·15078
35	1·15127	1·15177	1·15226	1·15276	1·15326	1·15375	1·15425	1·05475	1·15524	1·15574
36	1·15624	1·15674	1·15724	1·15773	1·15823	1·15873	1·15923	1·15973	1·16023	1·16073

CORRESPONDENCE BETWEEN BRIX AND SPECIFIC GRAVITY. $\frac{20°C.}{4°C.}$—*Continued.*

Degree Brix.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
37	1·16124	1·16174	1·16224	1·16274	1·15324	1·16375	1·16425	1·16476	1·16526	1·16576
38	1·16627	1·16677	1·16728	1·16779	1·16829	1·16880	1·16931	1·16981	1·17032	1·17083
39	1·17134	1·17185	1·17236	1·17287	1·17338	1·17389	1·17440	1·17491	1·17542	1·17593
40	1·17645	1·17696	1·17747	1·17799	1·17850	1·17901	1·17953	1·18004	1·18560	1·18108
41	1·18159	1·18211	1·18262	1·18314	1·18366	1·18418	1·18470	1·18521	1·18573	1·18625
42	1·18677	1·18729	1·18781	1·18833	1·18886	1·18938	1·18990	1·19042	1·19095	1·19147
43	1·19199	1·19252	1·19304	1·19356	1·19409	1·19462	1·19514	1·19567	1·19619	1·19672
44	1·19725	1·19777	1·19830	1·19883	1·19936	1·19989	1·20042	1·20095	1·20148	1·20201
45	1·20254	1·20307	1·20360	1·20414	1·20467	1·20520	1·20573	1·20627	1·20680	1·20733
46	1·20787	1·20840	1·20894	1·20945	1·21001	1·21055	1·21109	1·21162	1·21216	1·21270
47	1·21324	1·21378	1·21432	1·21486	1·21539	1·21594	1·21648	1·21702	1·21756	1·21810
48	1·21864	1·21918	1·21973	1·22027	1·22081	1·22136	1·22190	1·22245	1·22299	1·22354
49	1·22409	1·22463	1·22518	1·22573	1·22627	1·22682	1·22737	1·22792	1·22847	1·22902
50	1·22957	1·23012	1·23067	1·23122	1·23177	1·23232	1·23287	1·23343	1·23398	1·23453
51	1·23508	1·23564	1·23619	1·23675	1·23730	1·23786	1·23841	1·23897	1·23953	1·24008
52	1·24064	1·24120	1·24176	1·24231	1·24287	1·24343	1·24399	1·24452	1·24511	1·24567
53	1·24623	1·24679	1·24736	1·24792	1·24848	1·24905	1·24961	1·25017	1·25074	1·25130
54	1·25187	1·25243	1·25300	1·25356	1·25413	1·25470	1·25526	1·25583	1·25640	1·25897
55	1·25753	1·25810	1·25867	1·25924	1·25981	1·26038	1·26095	1·26153	1·26210	1·26267
56	1·26324	1·26382	1·26439	1·26496	1·26554	1·26611	1·26669	1·26726	1·26784	1·26841
57	1·26899	1·26956	1·27014	1·27072	1·27130	1·27188	1·27245	1·27303	1·27361	1·27419
58	1·27477	1·27535	1·27594	1·27652	1·27710	1·27768	1·27826	1·27884	1·27943	1·28001
59	1·28059	1·28118	1·28176	1·28235	1·28293	1·28352	1·28411	1·28469	1·28528	1·28587
60	1·28646	1·28704	1·28763	1·28822	1·28881	1·28940	1·28999	1·29058	1·29117	1·29176
61	1·29235	1·29295	1·29354	1·29413	1·29472	1·29532	1·29591	1·29651	1·29710	1·29770
62	1·29829	1·29889	1·29948	1·30008	1·30068	1·30127	1·30187	1·30247	1·30307	1·30367
63	1·30427	1·30487	1·30547	1·30607	1·30667	1·30727	1·30787	1·30847	1·30908	1·30968
64	1·31028	1·31088	1·31149	1·31209	1·31270	1·31330	1·31391	1·31451	1·31512	1·31573
65	1·31633	1·31694	1·31755	1·31816	1·31897	1·31937	1·31998	1·32059	1·32120	1·32184
66	1·32242	1·32304	1·32365	1·32426	1·32487	1·32548	1·32610	1·32671	1·32732	1·32795
67	1·32855	1·32917	1·32978	1·33040	1·33102	1·33163	1·33225	1·33287	1·33348	1·33410
68	1·33472	1·33534	1·33596	1·33658	1·33720	1·33782	1·33844	1·33906	1·33968	1·34031
69	1·34093	1·34155	1·34217	1·34280	1·34342	1·34405	1·34467	1·34530	1·34592	1·34655
70	1·34717	1·34780	1·34843	1·34905	1·34968	1·35031	1·35094	1·35157	1·35220	1·35283
71	1·35346	1·35409	1·35472	1·35535	1·35598	1·35661	1·35724	1·35788	1·35851	1·35914
72	1·35978	1·36041	1·36105	1·36168	1·36232	1·36295	1·36359	1·36423	1·36486	1·36550
73	1·36614	1·36678	1·36741	1·36805	1·36869	1·36933	1·36997	1·37061	1·37124	1·37189
74	1·37254	1·37318	1·37382	1·37446	1·37510	1·37575	1·37639	1·37704	1·37768	1·37833
75	1·37897	1·37962	1·38026	1·38091	1·38155	1·38220	1·38285	1·38350	1·38415	1·38480
76	1·38545	1·38610	1·38674	1·38740	1·38804	1·38870	1·38935	1·39000	1·39065	1·39130
77	1·39196	1·39261	1·39326	1·39392	1·39457	1·39523	1·39588	1·39654	1·39719	1·39785
78	1·39850	1·39916	1·39982	1·40048	1·40113	1·40179	1·40245	1·40311	1·40377	1·40443

CORRESPONDENCE BETWEEN BRIX AND SPECIFIC GRAVITY. $\frac{20°C.}{4°C.}$ — *Continued.*

Degree Brix.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
79	1·40509	1·40575	1·40641	1·40707	1·40773	1·40840	1·40906	1·40972	1·41039	1·41105
80	1·41175	1·41238	1·41304	1·41371	1·41437	1·41544	1·41571	1·41637	1·41704	1·41771
81	1·41837	1·41904	1·41971	1·42038	1·42105	1·42172	1·42239	1·42309	1·42373	1·42440
82	1·42507	1·42574	1·42642	1·42709	1·42776	1·42843	1·42911	1·42978	1·43046	1·43113
83	1·43181	1·43248	1·43316	1·43383	1·43451	1·43519	1·43587	1·43654	1·43722	1·43790
84	1·43858	1·43926	1·43994	1·44062	1·44130	1·44198	1·44266	1·44334	1·44402	1·44470
85	1·44539	1·44607	1·44675	1·44744	1·44812	1·44881	1·44939	1·45017	1·45086	1·45154
86	1·45223	1·45292	1·45360	1·45429	1·45499	1·45566	1·45636	1·45704	1·45773	1·45842
87	1·45911	1·45980	1·46049	1·46119	1·46189	1·46257	1·46326	1·46395	1·46464	1·46534
88	1·46603	1·46673	1·46742	1·46811	1·46881	1·46950	1·47020	1·47090	1·47159	1·47229
89	1·47299	1·47368	1·47438	1·47508	1·47578	1·47648	1·47718	1·47788	1·47857	1·47927
90	1·47998	1·48068	1·48138	1·48208	1·48278	1·48348	1·48419	1·48489	1·48559	1·48630
91	1·48700	1·48771	1·48841	1·48912	1·48982	1·49053	1·49123	1·49194	1·49265	1·49335
92	1·49406	1·49477	1·49548	1·49619	1·49690	1·49761	1·49832	1·49903	1·49974	1·50045
93	1·50116	1·50187	1 50258	1·50329	1·50401	1·50472	1·50543	1·50615	1·50686	1·50757
94	1·50829	1·50900	1·50972	1·51043	1·51115	1·51187	1·51258	1·51330	1·51402	1·51474
95	1·51545	1·51617	1·51689	1·51761	1·51833	1·51905	1·51987	1·52049	1·52121	1·52193
96	1·52266	1·52338	1·52410	1·42482	1·52555	1·52627	1·52699	1·52772	1·52844	1·52917
97	1 52989	1·53062	1·53134	1·53207	1·53279	1·53352	1·53425	1·53498	1·53570	1·53643
98	1·53716	1·53789	1·53862	1·53935	1·54008	1·54081	1·54154	1·54227	1·54300	1·54373
99	1·54446	1·54519	1·54593	1·54666	1·54729	1·54813	1·54886	1·54959	1·55033	1·55106
100	1·55180									

TEMPERATURE CORRECTIONS FOR BRIX HYDROMETER GRADUATED AT 17·5°C.

	Degrees Brix.												
	0	5	10	15	20	25	30	35	40	50	60	70	75
Temperature.	Subtract from the observed Reading												
15	0·09	0·11	0·12	0·14	0·14	0·15	0·16	0·17	0·16	0·17	0·19	0·21	0·25
16	0·06	0·07	0·08	0·09	0·10	0·10	0·11	0·12	0·12	0·12	0·14	0·16	0·18
17	0·02	0·02	0·03	0·03	0·03	0·04	0·04	0·04	0·04	0·04	0·05	0·05	0·06
Temperature.	Add to the observed Reading												
18	0·02	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·02
19	0·06	0·08	0·08	0·09	0·09	0·10	0·10	0·10	0·10	0·10	0·10	0·08	0·06
20	0·11	0·14	0·15	0·17	0 17	0·18	0·18	0·18	0·19	0·19	0·18	0·15	0·11
21	0·16	0·20	0·22	0·24	0·24	0·25	0·25	0·25	0·26	0·26	0·25	0·22	0·18
22	0·21	0·26	0·29	0·31	0·31	0·32	0·32	0·32	0·33	0·34	0·32	0·29	0·25
23	0·27	0·32	0·35	0·37	0·38	0·39	0·39	0 39	0·40	0·42	0·39	0·36	0·33
24	0·32	0·38	0·41	0·43	0·44	0·46	0·46	0·47	0·47	0·50	0·46	0·43	0·40
25	0·37	0·44	0·47	0·49	0·51	0·53	0·54	0·55	0·55	0·58	0·54	0·51	0·48
26	0·43	0·50	0·54	0·56	0·58	0·60	0·61	0·62	0·62	0·66	0·62	0·58	0·55
27	0·49	0·57	0·61	0·63	0·65	0·68	0·68	0·69	0·70	0·74	0·70	0·65	0·62
28	0·56	0·64	0·68	0·70	0·72	0·76	0·76	0·78	0·78	0·82	0·78	0·72	0·70
29	0·63	0·71	0·75	0·78	0·79	0·84	0·84	0·86	0·86	0·90	0·86	0·80	0·78
30	0·70	0·78	0·82	0·87	0·87	0·92	0·92	0·94	0·94	0·98	0·94	0·88	0·86
35	1·10	1·17	1·22	1·24	1·30	1·32	1·33	1·35	1·36	1·39	1·34	1·27	1·25
40	1·50	1·61	1·67	1·71	1·73	1·79	1·79	1·80	1·82	1·83	1·78	1·69	1·65
50		2·65	2·71	2·74	2·78	2·80	2·80	2·80	2·80	2·79	2·70	2·56	2·51
60		3·87	3·88	3·88	3·88	3·88	3·88	3·88	3·90	3·82	3·70	3·43	3·41
70		5·17	5·18	5·20	5·14	5·13	5·10	5·08	5·06	4·90	4·72	4·47	4·35
80			6·62	6·59	6·54	6·46	6·38	6·30	6·26	6·06	5·82	5·50	5·33
90			8·26	8·16	8·06	7·97	7·83	7·71	7·58	7·30	6·96	6·58	6·37
100			10·01	9·87	9·72	9·56	9·39	9·21	9·03	8·64	8·22	7·76	7·42

TEMPERATURE CORRECTIONS FOR BRIX HYDROMETER GRADUATED AT 27·5° C.

	DEGREES BRIX.									
	0	5	10	15	20	25	30	35	40	50
Temperature.	SUBTRACT FROM THE OBSERVED READING									
15	0·61	0·71	0·75	0·80	0·82	0·87	0·88	0·91	0·91	0·95
16	0·58	0·67	0·71	0·75	0·78	0·82	0·83	0·86	0·87	0·90
17	0·54	0·62	0·66	0·69	0·71	0·76	0·76	0·78	0·79	0·82
18	0·50	0·57	0·60	0·63	0·65	0·69	0·69	0·70	0·71	0·75
19	0·46	0·52	0·55	0·57	0·59	0·62	0·62	0·63	0·64	0·68
20	0·41	0·46	0·48	0·49	0·51	0·54	0·54	0·55	0·56	0·59
21	0·36	0·40	0·41	0·42	0·44	0·47	0·47	0·48	0·48	0·52
22	0·31	0·34	0·34	0·35	0·37	0·40	0·40	0·41	0·41	0·44
23	0·25	0·28	0·28	0·29	0·30	0·33	0·33	0·34	0·34	0·36
24	0·20	0·22	0·22	0·23	0·23	0·26	0·26	0·26	0·26	0·28
25	0·15	0·16	0·16	0·17	0·17	0·19	0·16	0·19	0·19	0·20
26	0·09	0·10	0·10	0·10	0·10	0·12	0·12	0·12	0·12	0·21
27	0·03	0·03	0·03	0·03	0·03	0·04	0·04	0·04	0·04	0·04
Temperature.	ADD TO THE OBSERVED READING									
28	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04
29	0·11	0·11	0·11	0·11	0·11	0·12	0·12	0·12	0·12	0·12
30	0·18	0·19	0·19	0·19	0·19	0·20	0·20	0·20	0·20	0·20
31	0·26	0·27	0·27	0·28	0·28	0·28	0·28	0·28	0·28	0·28
32	0·34	0·35	0·35	0·35	0·35	0·36	0·36	0·26	0·36	0·36
33	0·42	0·42	0·42	0·42	0·43	0·44	0·44	0·44	0·44	0·44
34	0·50	0·50	0·50	0·50	0·51	0·52	0·52	0·52	0·52	0·52
35	0·58	0·58	0·59	0·59	0·60	0·60	0·61	0·61	0·61	0·61

TABLE OF DRY SUBSTANCE FROM REFRACTIVE INDEX AT 28° C.

(H. C. Prinsen Geerligs.)

Index.	Per Cent Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.
1·3335	1·00	1·3405	5 70	1·3475	10·40	1·3545	14·95	1·3615	19·25
36	1·05	06	5·80	76	10·45	46	15 00	16	19 30
37	1·10	07	5·85	77	10·50	47	15·05	17	19·40
38	1·20	08	5 90	78	10·60	48	15·10	18	19·45
39	1 30	09	6·00	79	10·65	49	15·20	19	19·50
1·3340	1 35	1·3410	6·05	1·3480	10·70	1·3550	15·25	1·3620	19·60
41	1·40	11	6·10	81	10 80	51	15·30	21	19·65
42	1·50	12	6·20	82	10·85	52	15·40	22	19·70
43	1·60	13	6·25	83	10·90	53	15·45	23	19·75
44	1·65	14	6·30	84	11·00	54	15·50	24	19·80
45	1·70	15	6·40	85	11·05	55	15·60	25	19·85
46	1·80	16	6·45	86	11 10	56	15 65	26	19·90
47	1·85	17	6·50	87	11·20	57	15·70	27	20·00
48	1·90	18	6 60	88	11 25	58	15·75	28	20·05
49	2·00	19	6·65	89	11·30	59	15·80	29	20·10
1·3350	2·05	1·3420	6 70	1·3490	11 40	1·3560	15·85	1·3630	20·15
51	2·10	21	6·80	91	11·45	61	15 90	31	20·20
52	2·20	22	6·85	92	11·50	62	16·00	32	20·30
53	2 25	23	6·90	93	11·60	63	16·05	33	20·35
54	2·30	24	7·00	94	11·65	64	16·10	34	20·40
55	2·40	25	7·05	95	11·70	65	16·20	35	20 45
56	2·45	26	7·10	96	11·75	66	16·25	36	20·50
57	2·50	27	7·20	97	11·80	67	16 30	37	20·60
58	2·60	28	7·25	98	11·85	68	16·40	38	20·65
59	2·65	29	7·30	99	11·90	69	16 45	39	20 70
1.3360	2·70	1·3430	7·40	1·3500	12·00	1·3570	16·50	1·3640	20·80
61	2·80	31	7·45	01	12·05	71	16·60	41	20·85
62	2·85	32	7 50	02	12 10	72	16·65	42	20 90
63	2·90	33	7·60	03	12·20	73	16·70	43	20·95
64	3·00	34	7·65	04	12·25	74	16·75	44	21·00
65	3·05	35	7·70	05	12·30	75	16·80	45	21·05
66	3·10	36	7·80	06	12 40	76	16·85	46	21·10
67	3·20	37	7·85	07	12·45	77	16·90	47	21·15
68	3·25	38	7·90	08	12·50	78	17·00	48	21·20
69	3·30	39	8·00	09	12·60	79	17 05	49	21·30
1·3370	3·40	1·3440	8·05	1·3510	12·65	1·3580	17·10	1·3650	21·35
71	3·45	41	8·10	11	12·70	81	17 20	51	21·40
72	3·50	42	8·20	12	12·75	82	17·25	52	21·45
73	3·60	43	8·25	13	12·80	83	17·30	53	21·50
74	3·65	44	8 30	14	12·85	84	17·40	54	21·60
75	3·70	45	8·40	15	12·90	85	17·45	55	21·65
76	3·80	46	8·45	16	13·00	86	17·50	56	21·70
77	3·85	47	8·50	17	13·10	87	17 60	57	21 80
78	3·90	48	8·60	18	13·20	88	17·65	58	21·85
79	4·00	49	8 65	19	13·25	89	17·70	59	21·90
1·3380	4·05	1·3450	8·70	1·3520	13·30	1·3590	17·75	1·3660	21·95
81	4·10	51	8·80	21	13·40	91	17·80	61	22·00
82	4 20	52	8·85	22	13·45	92	17·85	62	22·05
83	4·25	53	8·90	23	13·50	93	17·90	63	22·10
84	4·30	54	9·00	24	13·60	94	18·00	64	22·15
85	4·40	55	9·05	25	13·65	95	18·05	65	22·20
86	4·45	56	9·10	26	13·70	96	18·10	66	22·30
87	4 50	57	9·20	27	13·80	97	18 15	67	22·35
88	4·60	58	9·25	28	13·85	98	18·20	68	22·40
89	4·65	59	9·30	29	13 90	99	18 30	69	22 45
1·3390	4·70	1·3460	9·40	1·3530	14·00	1·3600	18·35	1·3670	22·50
91	4·80	61	9·45	31	14·05	01	18·40	71	22·60
92	4·85	62	9·50	32	14 10	02	18·45	72	22·65
93	4·90	63	9·60	33	14·20	03	18·50	73	22·70
94	5·00	64	9 65	34	14·25	04	18·60	74	22·80
95	5·05	65	9·70	35	14·30	05	18·65	75	22·85
96	5·10	66	9·80	36	14 40	06	18 70	76	22·90
97	5·20	67	9·85	37	14·45	07	18·80	77	22 95
98	5·25	68	9·90	38	14·50	08	18·85	78	23·00
99	5·30	69	10·00	39	14·60	09	18·90	79	23·05
1·3400	5·40	1·3470	10·05	1·3540	14·65	1·3610	18·95	1·3680	23·10
01	5·45	71	10·10	41	14 70	11	19·00	81	23·15
02	5 50	72	10·20	42	14·80	12	19·05	82	23·20
03	5·60	73	10·25	43	14·85	13	19·10	83	23·30
04	5·65	74	10·30	44	14·90	14	19·20	84	23·35

TABLE OF DRY SUBSTANCE FROM REFRACTIVE INDEX AT 28° C.—*Continued.*

Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.
1·3685	23·40	1·3765	28·05	1·3845	32·50	1·3925	36·85	1·4005	41·10
86	23·45	66	28·10	46	32·55	26	36·90	06	41·15
87	23·50	67	28·15	47	32·60	27	36·95	07	41·20
88	23·60	68	28·20	48	32·65	28	37·00	08	41·25
89	23·65	69	28·30	49	32·70	29	37·05	09	41·30
1·3690	23·70	1·3770	28·35	1·3850	32·80	1·3930	37·10	1·4010	41·35
91	23·80	71	28·40	51	32·85	31	37·15	11	41·40
92	23·85	72	28·45	52	32·90	32	37·20	12	41·45
93	23·90	73	28·50	53	32·95	33	37·25	13	41·50
94	23·95	74	28·60	54	33·00	34	37·30	14	41·55
95	24·00	75	28·65	55	33·05	35	37·35	15	41·60
96	24·05	76	28·70	56	33·10	36	37·40	16	41·65
97	24·10	77	28·75	57	33·15	37	37·45	17	41·70
98	24·15	78	28·80	58	33·20	38	37·50	18	41·75
99	24·20	79	28·85	59	33·30	39	37·60	19	41·80
1·3700	24·30	1·3780	28·90	1·3860	33·35	1·3940	37·65	1·4020	41·85
01	24·35	81	28·95	61	33·40	41	37·70	21	41·90
02	24·40	82	29·00	62	33·45	42	37·75	22	41·95
03	24·45	83	29·05	63	33·50	43	37·80	23	42·00
04	24·50	84	29·10	64	33·55	44	37·85	24	42·05
05	24·60	85	29·15	65	33·60	45	37·90	25	42·10
06	24·65	86	29·20	66	33·65	46	37·95	26	42·15
07	24·70	87	29·30	67	33·70	47	38·00	27	42·20
08	24·80	88	29·35	68	33·80	48	38·05	28	42·25
09	24·85	89	29·40	69	33·85	49	38·10	29	42·30
1·3710	24·90	1·3790	29·45	1·3870	33·90	1·3950	38·15	1·4030	42·35
11	24·95	91	29·50	71	33·95	51	38·20	31	42·40
12	25·00	92	29·60	72	34·00	52	38·25	32	42·45
13	25·05	93	29·65	73	34·05	53	38·30	33	42·50
14	25·10	94	29·70	74	34·10	54	38·35	34	42·55
15	25·15	95	29·75	75	34·15	55	38·40	35	42·60
16	25·20	96	29·80	76	34·20	56	38·45	36	42·65
17	25·30	97	29·85	77	34·30	57	38·50	37	42·70
18	25·35	98	29·90	78	34·35	58	38·60	38	42·75
29	25·40	99	29·95	79	34·40	59	38·65	39	42·80
·3720	25·45	1·3800	30·00	1·3880	34·45	1·3960	38·70	1·4040	42·85
21	25·50	01	30·05	81	34·50	61	38·75	41	42·90
22	25·60	02	30·10	82	34·55	62	38·80	42	42·95
23	25·65	03	30·15	·83	34·60	63	38·85	43	43·00
24	25·70	04	30·20	84	34·65	64	38·90	44	43·05
25	25·80	05	30·30	85	34·70	65	38·95	45	43·10
26	25·85	06	30·35	86	34·80	66	39·00	46	43·15
27	25·90	07	30·40	87	34·85	67	39·05	47	43·20
28	25·95	08	30·45	88	34·90	68	39·10	48	43·25
39	26·00	09	30·50	89	34·95	69	39·15	49	43·30
1·3730	26·05	1·3810	30·55	1·3890	35·00	1·3970	39·20	1·4050	43·35
31	26·10	11	30·60	91	35·05	71	39·30	51	43·40
32	26·15	12	30·65	92	35·10	72	39·35	52	43·45
33	26·20	13	30·70	93	35·15	73	39·40	53	43·50
34	26·30	14	30·80	94	35·20	74	39·45	54	43·55
35	26·35	15	30·85	95	35·25	75	39·50	55	43·60
36	26·40	16	30·90	96	35·30	76	39·55	56	43·65
37	26·45	17	30·95	97	35·35	77	39·60	57	43·70
38	26·50	18	31·00	98	35·40	78	39·65	58	43·75
39	26·60	19	31·05	99	35·45	79	39·70	59	43·80
1·3740	26·65	1·3820	31·10	1·3900	35·50	1·3980	39·80	1·4060	43·85
41	26·70	21	31·15	01	35·60	81	39·85	61	43·90
42	26·80	22	31·20	02	35·65	82	39·90	62	43·95
43	26·85	23	31·30	03	35·70	83	39·95	63	44·00
44	26·90	24•	31·35	04	35·75	84	40·00	64	44·05
45	26·95	25	31·40	05	35·80	85	40·05	65	44·10
46	27·00	26	31·45	06	35·85	86	40·10	66	44·15
47	27·05	27	31·50	07	35·90	87	40·15	67	44·20
48	27·10	28	31·55	08	35·95	88	40·20	68	44·25
49	27·15	29	31·60	09	36·00	89	40·25	69	44·30
1·3750	27·20	1·3830	31·65	1·3910	36·05	1·3990	40·30	1·4070	44·35
51	27·30	31	31·70	11	36·10	91	40·35	71	44·40
52	27·35	32	31·80	12	36·15	92	40·40	72	44·45
53	27·40	33	31·85	13	36·20	93	40·45	73	44·50
54	27·45	34	31·90	14	36·25	94	40·50	74	44·55
55	27·50	35	31·95	15	36·30	95	40·60	75	44·60
56	27·60	36	32·00	16	36·35	96	40·65	76	44·65
57	27·65	37	32·05	17	36·40	97	40·70	77	44·70
58	27·70	38	32·10	18	36·45	98	40·75	78	44·75
59	27·75	39	32·15	19	36·50	99	40·80	79	44·80
1·3760	27·80	1·3840	32·20	1·3920	36·60	1·4000	40·85	1·4080	44·85
61	27·85	41	32·30	21	36·65	01	40·90	81	44·90
62	27·90	42	32·35	22	36·70	02	40·95	82	44·95
63	27·95	43	32·40	23	36·75	03	41·00	83	45·00
64	28·00	44	32·45	24	36·80	04	41·05	84	45·05

TABLE OF DRY SUBSTANCE FROM REFRACTIVE INDEX AT 28° C.—*Continued.*

Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.
1·4085	45·10	1·4165	48·95	1·4245	52·80	1·4325	56·50	1·4405	60·00
86	45·15	66	49·00	46	52 85	26	56·53	06	60·05
87	45·20	67	49·05	47	52·90	27	56·55	07	60·10
88	45·25	68	49·10	48	52 95	28	56·60	08	60·15
89	45·30	69	49·15	49	53·00	29	56 65	09	60·20
1·4090	45·35	1·4170	49·20	1·4250	53·05	1·4330	56·70	1·4410	60·23
91	45 40	71	49·25	51	53·10	31	56·75	11	60·25
92	45·45	72	49 30	52	53·15	32	56 80	12	60·30
93	45·50	73	49·35	53	53 20	33	56 83	13	60·35
94	45 53	74	49·40	54	53·25	34	56 85	14	60·40
95	45·55	75	49·45	55	53·30	35	56 90	15	60·45
96	45 60	76	49·50	56	53·35	36	56·95	16	60·50
97	45·65	77	49·55	57	53·40	37	57·00	17	60·53
98	45·70	78	49·60	58	53·45	38	57·05	18	60·55
99	45 75	79	49·65	59	53 50	39	57·10	19	60·60
1·4100	45 80	1·4180	49·70	1·4260	53 53	1·4340	57·15	1·4420	60·65
01	45·85	81	49·75	61	53·55	41	57·20	21	60·70
02	45·90	82	49·80	62	53 60	42	57 23	22	60·75
03	45·95	83	49·85	63	53·65	43	57·25	23	60·80
04	46·00	84	49·90	64	53·70	44	57·30	24	60·83
05	46·05	85	49·95	65	53·75	45	57·35	25	60·85
06	46·10	86	50·00	66	53·80	46	57·40	26	60·90
07	46·15	87	50·05	67	53 85	47	57·45	27	60·95
08	46·20	88	50·10	68	53·90	48	57·50	28	61·00
09	46·25	89	50·15	69	53·95	49	57·55	29	61·05
1·4110	46·30	1·4190	50·20	1·4270	54·00	1·4350	57·60	1·4430	61·10
11	46 35	91	50·25	71	54·05	51	57 65	31	61·15
12	46·40	92	50·30	72	54·10	52	57·70	32	61·20
13	46·45	93	50·35	73	54·15	53	57·73	33	61·23
14	46·50	94	50·40	74	54·20	54	57·75	34	61·25
15	46·55	95	50·45	75	54 23	55	57·80	35	61·30
16	46·60	96	50·50	76	54·25	56	57·85	36	61·35
17	46·65	97	50·53	77	54·30	57	57·90	37	61·40
18	46·70	98	50·55	78	54·35	58	57·95	38	61·45
19	46·75	99	50·60	79	54·40	59	58·00	39	61·50
1·4120	46·80	1·4200	50·65	1·4280	54 45	1·4360	58 05	1·4440	61·53
21	46·85	01	50·70	81	54·50	61	58 10	41	61·55
22	46·90	02	50·75	82	54 55	62	58·15	42	61·60
23	46·95	03	50 80	83	54·60	63	58 20	43	61·65
24	47·00	04	50 85	84	54 65	64	58·23	44	61·70
25	47 05	05	50 90	85	54·70	65	58 25	45	61·75
26	47·10	06	50 95	86	54·73	66	58·30	46	61·80
27	47·15	07	51·00	87	54·75	67	58 35	47	61·83
28	47 20	08	51 05	88	54·80	68	58·40	48	61·85
29	47·25	09	51·10	89	54 85	69	58 45	49	61·90
1·4130	47·30	1·4210	51·15	1·4290	54·90	1·4370	58·50	1·4450	61·95
31	47·35	11	51·20	91	54·95	71	58·53	51	62·00
32	47·40	12	51·25	92	55 00	72	58·55	52	62·05
33	47·45	13	51·30	93	55 05	73	58·60	53	62·10
34	47·50	14	51·35	94	55·10	74	58·65	54	62·15
35	47·53	15	51 40	95	55·15	75	58·70	55	62·20
36	47·55	16	51·45	96	55·20	76	58 75	56	62·23
37	47·60	17	51·50	97	55·23	77	58 80	57	62·25
38	47·65	18	51 53	98	55·25	78	58·83	58	62·30
39	47 70	19	51·55	99	55·30	79	58 85	59	62·35
1 4140	47·75	1·4220	51 60	1·4300	55 35	1·4380	58·90	1·4460	62·40
41	47·80	21	51·65	01	55·40	81	58·95	61	62·45
42	47·85	22	51 70	02	55·45	82	59·00	62	62·50
43	47·90	23	51·75	03	55 50	83	59·05	63	62·53
44	47 95	24	51 80	04	55·55	84	59·10	64	62·55
45	48·00	25	51·85	05	55·60	85	59·15	65	62·60
46	48·05	26	51·90	06	55·65	86	59 20	66	62·65
47	48 10	27	51·95	07	55·70	87	59·23	67	62·70
48	48·15	28	52·00	08	55·73	88	59·25	68	62 75
49	48·20	29	52·05	09	55·75	89	59 30	69	62·80
1·4150	48·25	1·4230	52·10	1·4310	55 80	1·4390	59·35	1·4470	62·83
51	48·30	31	52 15	11	55·85	91	59·40	71	62·85
52	48·35	32	52·20	12	55·90	92	59·45	72	62·90
53	48·40	33	52 25	13	55 95	93	59 50	73	62 95
54	48 45	34	52 30	14	56·00	94	59 53	74	63 00
55	48·50	35	52 35	15	56 05	95	59·55	75	63·05
56	48·53	36	52·40	16	56·10	96	59·60	76	63·10
57	48·55	37	52·45	17	56·15	97	59·65	77	63·15
58	48·60	38	52·50	18	56 20	98	59·70	78	63·20
59	48·65	39	52 53	19	56 23	99	59·75	79	63 23
1·4160	48·70	1·4240	52·55	1·4320	56·25	1·4400	59·80	1·4480	63·25
61	48·75	41	52·60	21	56 30	01	59·83	81	63·30
62	48·80	42	52·65	22	56·35	02	59·85	82	63·35
63	48·85	43	52·70	23	56·40	03	59·90	83	63·40
64	48·90	44	52·75	24	56·45	04	59·95	84	63 45

TABLE OF DRY SUBSTANCE FROM REFRACTIVE INDEX AT 28° C.—*Continued.*

Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.
1.4185	63·50	1.4565	66·90	1.4645	70·25	1.4725	73·55	1.4805	76·75
86	63·53	66	66·95	46	70·30	26	73·60	06	76·80
87	63·55	67	67·00	47	70·35	27	73·63	07	76·83
88	63·60	68	67·05	48	70·40	28	73·65	08	76·85
89	63·65	69	67·10	49	70·43	29	73·70	09	76·90
1.4190	63·70	1.4570	67·15	1.4650	70·45	1.4730	73·75	1.4810	76·95
91	63·75	71	67·20	51	70·50	31	73·80	11	77·00
92	63·80	72	67·23	52	70·55	32	73·83	12	77·03
93	63·83	73	67·25	53	70·60	33	73·85	13	77·05
94	63·85	74	67·30	54	70·63	34	73·90	14	77·10
95	63·90	75	67·35	55	70·65	35	73·95	15	77·15
96	63·95	76	67·40	56	70·70	36	74·00	16	77·20
97	64·00	77	67·43	57	70·75	37	74·03	17	77·23
98	64·05	78	67·45	58	70·80	38	74·05	18	77·25
99	64·10	79	67·50	59	70·83	39	74·10	19	77·30
1.4200	64·15	1.4580	67·55	1.4660	70·85	1.4740	74·15	1.4820	77·35
01	64·20	81	67·60	61	70·90	41	74·20	21	77·40
02	64·23	82	67·63	62	70·95	42	74·23	22	77·43
03	64·25	83	67·65	63	71·00	43	74·25	23	77·45
04	64·30	84	67·70	64	71·05	44	74·30	24	77·50
05	64·35	85	67·75	65	71·10	45	74·35	25	77·55
06	64·40	86	67·80	66	71·15	46	74·40	26	77·60
07	64·45	87	67·83	67	71·20	47	74·43	27	77·63
08	64·50	88	67·85	68	71·23	48	74·45	28	77·65
09	64·55	89	67·90	69	71·25	49	74·50	29	77·70
1.4210	64·60	1.4590	67·95	1.4670	71·30	1.4750	74·55	1.4830	77·75
11	64·65	91	68·00	71	71·35	51	74·60	31	77·80
12	64·70	92	68·05	72	71·40	52	74·63	32	77·83
13	64·73	93	68·10	73	71·43	53	74·65	33	77·85
14	64·75	94	68·15	74	71·45	54	74·70	34	77·90
15	64·80	95	68·20	75	71·50	55	74·75	35	77·95
16	64·85	96	68·23	76	71·55	56	74·80	36	78·00
17	64·88	97	68·25	77	71·60	57	74·83	37	78·03
18	64·90	98	68·30	78	71·63	58	74·85	38	78·05
19	64·95	99	68·35	79	71·65	59	74·90	39	78·10
1.4220	65·00	1.4600	68·40	1.4680	71·70	1.4760	74·95	1.4840	78·15
21	65·05	01	68·43	81	71·75	61	75·00	41	78·20
22	65·10	02	68·45	82	71·80	62	75·03	42	78·23
23	65·13	03	68·50	83	71·83	63	75·05	43	78·25
24	65·15	04	68·55	84	71·85	64	75·10	44	78·30
25	65·20	05	68·60	85	71·90	65	75·15	45	78·35
26	65·23	06	68·63	86	71·95	66	75·20	46	78·40
27	65·25	07	68·65	87	72·00	67	75·23	47	78·43
28	65·30	08	68·70	88	72·05	68	75·25	48	78·45
29	65·35	09	68·75	89	72·10	69	75·30	49	78·50
1.4230	65·40	1.4610	68·80	1.4690	72·15	1.4770	75·35	1.4850	78·53
31	65·45	11	68·83	91	72·20	71	75·40	51	78·55
32	65·50	12	68·85	92	72·23	72	75·43	52	78·60
33	65·55	13	68·90	93	72·25	73	75·45	53	78·63
34	65·60	14	68·95	94	72·30	74	75·50	54	78·65
35	65·63	15	69·00	95	72·35	75	75·55	55	78·70
36	65·65	16	69·05	96	72·40	76	75·60	56	78·75
37	65·70	17	69·10	97	72·43	77	75·63	57	78·80
38	65·75	18	69·15	98	72·45	78	75·65	58	78·83
39	65·80	19	69·20	99	72·50	79	75·70	59	78·85
1.4240	65·85	1.4620	69·23	1.4700	72·55	1.4780	75·75	1.4860	78·90
41	65·90	21	69·25	01	72·60	81	75·80	61	78·95
42	65·95	22	69·30	02	72·63	82	75·83	62	79·00
43	66·00	23	69·35	03	72·65	83	75·85	63	79·03
44	66·05	24	69·40	04	72·70	84	75·90	64	79·05
45	66·10	25	69·43	05	72·75	85	75·95	65	79·10
46	66·15	26	69·45	06	72·80	86	76·00	66	79·15
47	66·20	27	69·50	07	72·83	87	76·03	67	79·20
48	66·23	28	69·55	08	72·85	88	76·05	68	79·23
49	66·25	29	69·60	09	72·90	89	76·10	69	79·25
1.4250	66·30	1.4630	69·63	1.4710	72·95	1.4790	76·15	1.4870	79·30
51	66·35	31	69·65	11	73·00	91	76·20	71	79·35
52	66·40	32	69·70	12	73·03	92	76·23	72	79·40
53	66·43	33	69·75	13	73·05	93	76·25	73	79·43
54	66·45	34	69·80	14	73·10	94	76·30	74	79·45
55	66·50	35	69·83	15	73·15	95	76·35	75	79·50
56	66·55	36	69·85	16	73·20	96	76·40	76	79·53
57	66·60	37	69·90	17	73·23	97	76·43	77	79·55
58	66·63	38	69·95	18	73·25	98	76·45	78	79·60
59	66·65	39	70·00	19	73·30	99	76·50	79	79·63
1.4260	66·70	1.4640	70·05	1.4720	73·35	1.4800	76·55	1.4880	79·65
61	66·75	41	70·10	21	73·40	01	76·60	81	79·70
62	66·80	42	70·15	22	73·43	02	76·63	82	79·75
63	66·83	43	70·20	23	73·45	03	76·65	83	79·80
64	66·85	44	70·23	24	73·50	04	76·70	84	79·83

Table of Dry Substance from Refractive Index at 28° C.—*Continued.*

Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.	Index.	Per Cent. Dry Substance.
1·4885	79·85	1·4945	82·20	1·5005	84·50	1·5065	86·70	1·5125	88·93		
86	79·90	46	82·23	06	84·53	66	86·75	26	88·95		
87	79·95	47	82·25	07	84·55	67	86·80	27	89·00		
88	80·00	48	82·30	08	84·60	68	86·83	28	89·03		
89	80·03	49	82·35	09	84·63	69	86·85	29	89·05		
1·4890	80·05	1·4950	82·40	1·5010	84·65	1·5070	86·90	1·5130	89·10		
91	80·10	51	82·43	11	84·70	71	86·93	31	89·13		
92	80·15	52	82·45	12	84·75	72	86·95	32	89·15		
93	80·20	53	82·50	13	84·80	73	87·00	33	89·20		
94	80·23	54	82·53	14	84·83	74	87·03	34	89·23		
95	80·25	55	82·55	15	84·85	75	87·05	35	86·25		
96	80·30	56	82·60	16	84·90	76	87·10	36	89·30		
97	80·35	57	82·63	17	84·93	77	87·15	37	89·35		
98	80·40	58	82·65	18	84·95	78	87·20	38	89·40		
99	80·43	59	82·70	19	85·00	79	87·23	39	89·43		
1·4900	80·45	1·4960	82·75	1·5020	85·03	1·5080	87·25	1·5140	89·45		
01	80·50	61	82·80	21	85·05	81	87·30	41	89·50		
02	80·53	62	82·83	22	85·10	82	87·33	42	89·53		
03	80·55	63	82·85	23	85·15	83	87·35	43	89·55		
04	80·60	64	82·90	24	85·20	84	87·40	44	89·60		
05	80·63	65	82·95	25	85·23	85	87·45	45	89 63		
06	80·65	66	83·00	26	85·25	86	87·50	46	89·65		
07	80·70	67	83·03	27	85·30	87	87·53	47	89·70		
08	80·75	68	83·05	28	85·33	88	87·55	48	89·75		
09	80·80	69	83·10	29	85·35	89	87·60	49	89·80		
1·4910	80·83	1·4970	83·15	1·5030	85·40	1·5090	87·63	1·5150	89·83		
11	80·85	71	83·20	31	85·45	91	87·65	51	89·85		
12	80·90	72	83·23	32	85·50	92	87·70	52	89·90		
13	80·95	73	83·25	33	85·53	93	87·75	53	89·93		
14	81·00	74	83·30	34	85·55	94	87·80	54	89·95		
15	81·03	75	83·35	35	85·60	95	87·83	55	90·00		
16	81·05	76	83·40	36	85·63	96	87·85	56	90·03		
17	81·10	77	83·43	37	85·65	97	87·90	57	90·05		
18	81·15	78	83·45	38	85·70	98	87·93	58	90·10		
19	81·20	79	83·50	39	85·75	99	87·95	59	90·13		
1·4920	81·23	1·4980	83·53	1·5040	85·80	1·5100	88·00	1·5160	90·15		
21	81·25	81	83·55	41	85·83	01	88·03	61	90·20		
22	81·30	82	83·60	42	85·85	02	88·05	62	90·25		
23	81·35	83	83·63	43	85·90	03	88·10	63	90·30		
24	81·40	84	83·65	44	85·93	04	88·15	64	90·33		
25	81·43	85	83·70	45	85·95	05	88·20	65	90·35		
26	81·45	86	83·75	46	86·00	06	88·23	66	90·40		
27	81·50	87	83·80	47	86·03	07	88·25	67	90·43		
28	81·53	88	83·83	48	86·05	08	88·30	68	90·45		
29	81·55	89	83·85	49	86·10	09	88·33	69	90·50		
1·4930	81·60	1·4990	83·90	1·5050	86·15	1·5110	88·35	1·5170	90·53		
31	81·63	91	83·95	51	86·20	11	88·40	71	90·55		
32	81·65	92	84·00	52	86·23	12	88·45	72	90·60		
33	81·70	93	84·03	53	86·25	13	88·50	73	90·63		
34	81·75	94	84·05	54	86·30	14	88 53	74	90·65		
35	81·80	95	84·10	55	86·33	15	88·55	75	90·70		
36	81·83	96	84·15	56	86·35	16	88·60	76	90·75		
37	81·85	97	84·20	57	86·40	17	88·63	77	90·80		
38	81·90	98	84·23	58	86·45	18	88·65	78	90·83		
39	81·95	99	84·25	59	86·50	19	88·70	79	90·85		
1·4940	82·00	1·5000	84·30	1·5060	86·53	1·5120	88·75	1·5180	90·90		
41	82·03	01	84·33	61	86·55	21	88·80	81	90·93		
42	82·05	02	84·35	62	86·60	22	88·83	82	90·95		
43	82·10	03	84·40	63	86·63	23	88·85				
44	82·15	04	84·45	64	86·65	24	88·90				

TABLE OF CORRECTIONS FOR THE TEMPERATURE.

DRY SUBSTANCE.

Temperature of the prisms in °C.	0	5	10	15	20	25	30	40	50	60	70	80	90

SUBTRACT.

	0	5	10	15	20	25	30	40	50	60	70	80	90
20° C	·53	·54	·55	·56	·57	·58	·60	·62	·64	·62	·61	·60	·58
21	·46	·47	·48	·49	·50	·51	·52	·54	·56	·54	·53	·52	·50
22	·40	·41	·42	·42	·43	·44	·45	·47	·48	·47	·46	·45	·44
23	·33	·33	·34	·35	·36	·37	·38	·39	·40	·39	·38	·38	·38
24	·26	·26	·27	·28	·28	·29	·30	·31	·32	·31	·31	·30	·30
25	·20	·20	·21	·21	·22	·22	·23	·23	·24	·23	·23	·23	·22
26	·12	·12	·13	·14	·14	·14	·15	·15	·16	·16	·16	·15	·14
27	·07	·07	·07	·07	·07	·07	·08	·08	·08	·08	·08	·08	·07

ADD.

	0	5	10	15	20	25	30	40	50	60	70	80	90
29° C	·07	·07	·07	·07	·07	·07	·08	·08	·08	·08	·08	·08	·07
30	·12	·12	·13	·14	·14	·14	·15	·15	·16	·16	·16	·15	·14
31	·20	·20	·21	·21	·22	·22	·23	·23	·24	·23	·23	·23	·22
32	·26	·26	·27	·28	·28	·29	·30	·31	·32	·31	·31	·30	·30
33	·33	·33	·34	·35	·36	·37	·38	·39	·40	·39	·38	·38	·38
34	·40	·41	·42	·42	·43	·44	·45	·47	·48	·47	·46	·45	·44
35	·46	·47	·48	·49	·50	·51	·52	·54	·56	·54	·53	·52	·50

TABLE OF THE DENSITY OF WATER.

Temperature. °C.	Volume.	Temperature. °C.	Volume.
4	1·00000	55	·98579
10	·99974	60	·98331
15	·99913	65	·98067
20	·99825	70	·97790
25	·99710	75	·97495
30	·99571	80	·97191
35	·99410	85	·96876
40	·99233	90	·96550
45	·99035	95	·96212
50	·98813	100	·95803

APPENDIX.

TABLE OF THE

ELEVATION OF THE BOILING POINT OF SUGAR SOLUTIONS

(Claassen).

Per cent. Sugar.	Elevation of the boiling point F°	Per cent. Sugar.	Elevation of the boiling point F°
75·	13·2	86·75	31·1
75·5	13·7	87·	31·8
76·	14·2	87·25	32·5
76·5	14·8	87·5	33·2
77·	15·3	87·75	33·9
77·5	15·8	88·	34·6
78·	16·4	88·25	35·3
78·5	16·9	88·5	36·0
79·	17·5	88·75	36·7
79·5	18·0	89·	37·5
80·	18·6	89·25	38·3
80·5	19·3	89·5	39·1
81·	19·9	89·75	39·9
81·5	20·5	90·	40·7
82·	21·2	90·25	41·5
82·5	22·0	90·5	42·4
83·	22·7	90·75	43·2
83·5	23·6	91·	44·1
84·	24·7	91·25	45·1
84·5	25·7	91·5	46·3
85·	26·8	91·75	47·7
85·5	27·9	92·	50·2
86·	29·2		
86·25	29·8		
86·5	30·4		

TABLE SHOWING THE EXPANSION OF SUGAR SOLUTIONS.

(Gerlach.)

Temperature C°.	10 per cent.	20 per cent.	30 per cent.	40 per cent.	50 per cent.
0	1·0000	1·0000	1·0000	1·0000	1·0000
5	1·0004	1·0007	1·0009	1·0012	1·0016
10	1·0012	1·0016	1·0021	1·0026	1·0032
15	1·0021	1·0028	1·0034	1·0042	1·0050
20	1·0033	1·0041	1·0049	1·0058	1·0069
25	1·0048	1·0057	1·0066	1·0075	1·0088
30	1·0064	1·0074	1·0084	1·0094	1·0110
35	1·0082	1·0092	1.0103	1·0114	1·0132
40	1·0101	1·0112	1·0124	1·0136	1·0156
45	1·0122	1·0134	1·0146	1·0160	1·0180
50	1·0145	1·0156	1·0170	1·0184	1·0204
55	1·0170	1·0183	1·0196	1·0210	1·0229
60	1·0197	1·0209	1·0222	1·0235	1·0253
65	1·0225	1·0236	1·0249	1·0261	1·0278
70	1·0255	1·0265	1·0277	1·0287	1·0306
75	1·0284	1·0295	1·0306	1·0316	1·0332
80	1·0316	1·0325	1·0335	1·0345	1·0360
85	1·0347	1·0355	1·0365	1·0375	1·0388
90	1·0379	1·0387	1·0395	1·0405	1·0417
95	1·0411	1·0418	1·0425	1·0435	1·0445
100	1·0442	1.0450	1·0456	1·0465	1·0477

TABLE GIVING THE PERCENTAGES BY WEIGHT, PER CENT., ON ORIGINAL JUICE EVAPORATED BETWEEN DIFFERENT DEGREES BRIX OR BEAUMÉ.

Initial Density.—Degree Brix in Upper, Degree Beaumé in Lower Line.

Final Density Degree Brix	Final Density Degree Beaumé	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		5·7	6·2	6·8	7·4	7·9	8·5	9·0	9·6	10·1	10·7	11·3	11·8	12·4	13·0	13·5	14·1
35	19·6	71·43	68·57	65·71	62·86	60·00	57·14	54·29	51·43	48·87	45·71	42·86	40·00	37·15	34·29	31·43	28·57
36	20·1	72·33	69·45	66·68	63·90	61·11	58·33	55·56	52·78	50·00	47·23	44·45	41·67	38·90	36·12	33·34	30·56
37	20·7	73·00	70·27	67·57	64·86	62·16	59·46	56·75	54·05	57·35	48·65	45·95	43·23	40·53	38·13	35·13	32·42
38	21·2	73·70	71·07	68·44	65·81	63·17	60·52	57·89	55·26	52·63	50·00	47·37	44·74	42·11	39·45	36·85	34·22
39	21·8	74·36	71·79	69·23	66·66	64·10	61·54	58·97	56·41	53·81	51·28	48·72	46·16	43·60	41·03	38·47	35·90
40	22·3	75·00	72·50	70·00	67·50	65·00	62·50	60·00	57·50	55·00	52·50	50·00	47·50	45·00	42·50	40·00	37·50
41	22·9	75·61	73·17	70·73	68·29	65·84	63·41	60·97	58·53	56·09	53·66	51·22	48·78	46·34	43·90	41·46	39·02
42	23·4	76·19	73·81	71·43	69·06	66·67	64·29	61·91	59·53	57·17	54·76	52·38	50·00	47·62	44·24	42·86	40·48
43	23·9	76·74	74·42	72·09	69·76	67·44	65·12	62·79	60·46	58·14	55·81	53·48	51·16	48·84	46·51	44·19	41·86
44	24·5	77·35	75·08	73·80	71·53	68·25	65·98	63·70	61·43	59·15	56·88	54·60	52·32	50·05	47·78	45·50	43·13
45	25·0	77·78	75·55	73·33	71·11	68·89	66·67	64·44	62·22	60·00	57·89	55·55	53·33	51·11	48·89	46·67	44·44
46	25·6	78·26	76·08	73·92	71·74	69·57	67·39	65·22	63·04	50·94	58·77	56·52	54·35	52·17	50·00	47·83	45·64
47	26·1	78·72	76·59	74·47	72·34	70·21	68·00	65·96	63·83	61·70	59·57	57·44	55·32	53·19	51·06	48·93	46·81
48	26·6	79·17	77·03	75·00	72·92	70·83	68·75	66·67	64·58	62·50	60·42	58·33	56·25	54·17	52·08	50·00	47·92
49	27·2	79·52	77·55	75·56	73·47	71·43	69·32	67·35	65·30	63·26	61·22	59·18	57·15	55·11	53·07	51·02	48·98
50	27·7	80·00	78·00	76·00	74·00	72·55	70·00	68·00	66·00	64·03	62·00	60·00	58·00	56·00	54·00	52·00	50·00
51	28·2	80·39	78·43	76·47	74·51	72·55	70·59	68·62	66·66	64·70	62·75	60·78	58·82	56·86	54·90	52·94	50·98
52	28·8	80·77	78·84	76·92	75·00	73·07	71·15	69·23	67·31	65·38	63·46	61·54	59·61	57·59	55·77	53·85	51·92
53	29·3	81·13	79·26	77·36	75·46	73·58	71·61	69·81	67·92	66·03	64·15	62·25	50·37	58·49	56·60	54·71	52·83
54	29·8	81·49	79·64	77·78	75·93	74·08	72·23	70·38	68·52	66·67	64·82	62·97	61·12	59·26	57·41	55·56	53·71
55	30·4	81·82	80·00	78·18	76·36	74·54	72·72	70·91	69·09	67·27	65·45	63·63	61·81	59·50	58·18	56·36	54·54
56	30·9	82·14	80·36	78·57	76·79	75·00	73·21	71·43	69·54	67·86	66·07	64·29	62·50	60·71	58·93	57·14	54·36
57	31·4	82·45	80·70	78·95	77·19	75·43	73·68	71·93	70·17	68·42	66·66	64·91	63·13	61·38	59·63	57·88	56·13
58	31·9	82·75	81·03	79·30	77·58	75·86	74·13	72·41	70·68	68·96	67·24	65·51	63·79	62·06	60·34	58·62	56·89
59	32·5	83·04	81·35	79·66	77·97	76·27	74·58	72·88	71·18	69·49	67·80	66·10	64·41	62·72	61·02	59·32	57·63
60	33·0	83·33	81·67	80·00	78·33	76·67	75·00	72·33	71·67	70·00	68·33	66·67	65·00	63·33	61·67	60·00	58·33

EQUIVALENTS OF COPPER AND DEXTROSE FOR ALLIHN'S METHOD.

Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.
11	6·6	41	21·4	71	36·3	101	51·4
12	7·1	42	21·9	72	36·8	102	51·9
13	7·6	43	22·4	73	37·3	103	52·4
14	8·1	44	22·9	74	37·8	104	52·9
15	8·6	45	23·4	75	38·3	105	53·5
16	9·0	46	23·9	76	38·8	106	54·0
17	9·5	47	24·4	77	39·3	107	54·5
18	10·0	48	24·9	78	39·8	108	55·0
19	10·5	49	25·4	79	40·3	109	55·5
20	11·0	50	25·9	80	40·8	110	56·0
21	11·5	51	26·4	81	41·3	111	56·5
22	12·0	52	26·9	82	41·8	112	57·0
23	12·5	53	27·4	83	42·3	113	57·5
24	13·0	54	27·9	84	42·8	114	58·0
25	13·5	55	28·4	85	43·4	115	58·6
26	14·0	56	28·8	86	43·9	116	59·1
27	14·5	57	29·3	87	44·4	117	59·6
28	15·0	58	29·8	88	44·9	118	60·1
29	15·5	59	30·3	89	45·4	119	60·6
30	16·0	60	30·8	90	45·9	120	61·1
31	16·5	61	31·3	91	46·4	121	61·6
32	17·0	62	31·8	92	46·9	122	62·1
33	17·5	63	32·3	93	47·4	123	62·6
34	18·0	64	32·8	94	47·9	124	63·1
35	18·5	65	33·3	95	48·4	125	63·7
36	18·9	66	33·8	96	48·9	126	64·2
37	19·4	67	34·3	97	49·4	127	64·7
38	19·9	68	34·8	98	49·9	128	65·2
39	20·4	69	35·3	99	50·4	129	65·7
40	20·9	70	35·8	100	50·9	130	66·2

EQUIVALENTS OF COPPER AND DEXTROSE FOR ALLIHN'S METHOD.—*Continued.*

Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.
131	66·7	166	84·8	201	103·1	236	121·7
132	67·2	167	85·3	202	103·7	237	122·3
133	67·7	168	85·9	203	104·2	238	122·8
134	68·2	169	86·4	204	104·7	239	123·4
135	68·8	170	86·9	205	105·3	240	123·9
136	69·3	171	87·4	206	105·8	241	124·4
137	69·8	172	87·9	207	106·3	242	125·0
138	70·3	173	88·5	208	106·8	243	125·5
139	70·8	174	89·0	209	107·4	244	126·0
140	71·3	175	89·5	210	107·9	245	126·6
141	71·8	176	90·0	211	108·4	246	127·1
142	72·3	177	90·5	212	109·0	247	127·6
143	72·9	178	91·1	213	109·5	248	128·1
144	73·4	179	91·6	214	110·0	249	128·7
145	73·9	180	92·1	215	110·6	250	129·2
146	74·4	181	92·6	216	111·1	251	129·7
147	74·9	182	93·1	217	111·6	252	130·3
148	75·5	183	93·7	218	112·1	253	130·8
149	76·0	184	94·2	219	112·7	254	131·4
150	76·5	185	94·7	220	113·2	255	131·9
151	77·0	186	95·2	221	113·7	256	132·4
152	77·5	187	95·7	222	114·3	257	133·0
153	78·1	188	96·3	223	114·8	258	133·5
154	78·6	189	96·8	224	115·3	259	134·1
155	79·1	190	97·3	225	115·9	260	134·6
156	79·6	191	97·8	226	116·4	261	135·1
157	80·1	192	98·4	227	116·9	262	135·7
158	80·7	193	98·9	228	117·4	263	136·2
159	81·2	194	99·4	229	118·0	264	136·8
160	81·7	195	100·0	230	118·5	265	137·3
161	82·2	196	100·5	231	119·0	266	137·8
162	82·7	197	101·0	232	119·6	267	138·4
163	83·3	198	101·5	233	120·1	268	138·9
164	83·8	199	102·0	234	120·7	269	139·5
165	84·3	200	102·6	235	121·2	270	140·0

EQUIVALENTS OF COPPER AND DEXTROSE FOR ALLIHN'S METHOD.—*Continued.*

Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.
271	140·6	306	159·8	341	179·3	376	199·1
272	141·1	307	160·4	342	179·8	377	199·7
273	141·7	308	160·9	343	180·4	378	200·3
274	142·2	309	161·5	344	180·9	379	200·8
275	142·8	310	162·0	345	181·5	380	201·4
276	143·3	311	162·6	346	182·1	381	202·0
277	143·9	312	163·1	347	182·6	382	202·5
278	144·4	313	163·7	348	183·2	383	203·1
279	145·0	314	164·2	349	183·7	384	203·7
280	145·5	315	164·8	350	184·3	385	204·3
281	146·1	316	165·3	351	184·9	386	204·8
282	146·6	317	165·9	352	185·4	387	205·4
283	147·2	318	166·4	353	186·0	388	206·0
284	147·7	319	167·0	354	186·6	389	206·5
285	148·3	320	167·5	355	187·2	390	207·1
286	148·8	321	168·1	356	187·7	391	207·7
287	149·4	322	168·6	357	188·3	392	208·3
288	149·9	323	169·2	358	188·9	393	208·8
289	150·5	324	169·7	359	189·4	394	209·4
290	151·0	325	170·3	360	190·0	395	210·0
291	151·6	326	170·9	361	190·6	396	210·6
292	152·1	327	171·4	362	191·1	397	211·2
293	152·7	328	172·0	363	191·7	398	211·7
294	153·2	329	172·5	364	192·3	399	212·3
295	153·8	330	173·1	365	192·9	400	212·9
296	154·3	331	173·7	366	193·4	401	213·5
297	154·9	332	174·2	367	194·0	402	214·1
298	155·4	333	174·8	368	194·6	403	214·6
299	156·0	334	175·3	369	195·1	404	215·2
300	156·5	335	175·9	370	195·7	405	215·8
301	157·1	336	176·5	371	196·3	406	216·4
302	157·6	337	177·0	372	196·8	407	217·0
303	158·2	338	177·6	373	197·4	408	217·5
304	158·7	339	178·1	374	198·0	409	218·1
305	159·3	340	178·7	375	198·6	410	218·7

EQUIVALENTS OF COPPER AND DEXTROSE FOR ALLIHN'S METHOD.—*Continued*.

Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.	Milli-grams of Copper.	Milli-grams of Dextrose.
411	219·3	426	228·0	441	236·9	456	245·7
412	219·9	427	228·6	442	237·5	457	246·3
413	220·4	428	229·2	443	238·1	458	246·9
414	221·0	429	229·8	444	238·7	459	247·5
415	221·6	430	230·4	445	239·3	460	248·1
416	222·2	431	231·0	446	239·8	461	248·7
417	222·8	432	231·6	447	240·4	462	249·3
418	223·3	433	232·2	448	241·0	463	249·9
419	223·9	434	232·8	449	241·6		
420	224·5	435	233·4	450	242·2		
421	225·1	436	233·9	451	242·8		
422	225·7	437	234·5	452	243·4		
423	226·3	438	235·1	453	244·0		
424	226·9	439	235·7	454	244·6		
425	227·5	440	236·3	455	245·2		

SODIUM CARBONATE AT 82·50° F.

(Schiff.)

Specific Gravity.	Percentage of Na₂CO₃ 10H₂O.	Percentage of Na₂CO₃.	Specific Gravity.	Percentage of Na₂CO₃. 10H₂O.	Percentage of Na₂CO₃.
1·0038	1	·370	1·1035	26	9·635
1·0076	2	·741	1·1076	27	10·005
1·0114	3	1·112	1·1117	28	10·376
1·0153	4	1·482	1·1158	29	10·746
1·0192	5	1·853	1·1210	30	11·118
1·0231	6	2·223	1·1242	31	11·448
1·0270	7	2·574	1·1284	32	11·859
1·0309	8	2·965	1·1326	33	12·230
1·0348	9	3·335	1·1368	34	12·600
1·0388	10	3·706	1·1410	35	12·971
1·0428	11	4·076	1·1452	36	13·341
1·0468	12	4·447	1·1494	37	13·712
1·0508	13	4·817	1·1536	38	14·082
1·0548	14	5·188	1·1578	39	14·453
1·0588	15	5·558	1·1620	40	14·824
1·0628	16	5·928	1·1662	41	15·195
1·0668	17	6·299	1·1704	42	15·566
1·0708	18	6·670	1·1746	43	15·936
1·0748	19	7·041	1·1788	44	16·307
1·0789	20	7·412	1·1830	45	16·677
1·0830	21	7·782	1·1873	46	17·048
1·0871	22	8·153	1·1916	47	17·418
1·0912	23	8·523	1·1959	48	17·789
1·0953	24	8·894	1·2002	49	18·159
1·0994	25	9·264	1·2045	50	18·530

APPENDIX.

CAUSTIC SODA AT 82·5° F.

(Geerligs.)

Percentage of Soda.	Specific Gravity of a percentage of Na_2O.	Specific Gravity of a percentage of NaOH.	Percentage of Soda.	Specific Gravity of a percentage of Na_2O.	Specific Gravity of a percentage of NaOH.
1	1·012	1·009	31	1·434	1·339
2	1·027	1·020	32	1·446	1·347
3	1·040	1·032	33	1·458	1·359
4	1·055	1·043	34	1·471	1·370
5	1·071	1·056	35	1·484	1·380
6	1·086	1·067	36	1·496	1·391
7	1·101	1·078	37	1·511	1·401
8	1·116	1·089	38	1·526	1·411
9	1·129	1·100	39	1·539	1·422
10	1·142	1·112	40	1·554	1·433
11	1·158	1·123	41	1·566	1·443
12	1·172	1·133	42	1·579	1·452
13	1·187	1·145	43	1·593	1·464
14	1·200	1·156	44	1·606	1·474
15	1·215	1·167	45	1·617	1·484
16	1·230	1·178	46	1·632	1·495
17	1·241	1·184	47	1·645	1·503
18	1·254	1·198	48	1·658	1·514
19	1·266	1·209	49	1·673	1·524
20	1·284	1·221	50	1·685	1·535
21	1·296	1·234	51	1·700	1·545
22	1·311	1·243	52	1·714	1·555
23	1·325	1·254	53	1·725	1·565
24	1·337	1·265	54	1·740	1·575
25	1·351	1·275	55	1·755	1·586
26	1·365	1·286	56	1·770	1·596
27	1·374	1·296	57	1·780	1·606
28	1·391	1·306	58	1·795	1·617
29	1·406	1·317	59	1·810	1·628
30	1·420	1·328	60	1·825	1·638

TABLE SHOWING THE SOLUBILITY OF SUGAR IN WATER.

(Herzfeld.)

Temperature. C°.	Sugar per cent.	Temperature. C°.	Sugar per cent.	Temperature. C°.	Sugar per cent.
0	64·18	35	69·55	70	76·22
5	64·87	40	70·42	75	77·27
10	65·58	45	71·32	80	78·36
15	66·53	50	72·25	85	79·46
20	67·09	55	73·20	90	80·61
25	67·89	60	74·18	95	81·77
30	68·80	65	75·88	100	82·97

TABLE SHOWING THE SOLUBILITY OF LIME IN SUGAR SOLUTIONS.

Sugar in 100 parts of Water.	Density of Syrup.	Density after Saturation with Lime.	Residue dried at 120° C. Per cent. of Lime.	Residue dried at 120° C. Per cent. of Sugar.
5	1·018	1·026	15·3	84·7
10	1·036	1·053	18·1	81·9
15	1·052	1·080	18·5	81·5
20	1·068	1·104	18·8	81·2
25	1·082	1·128	19·8	80·2
30	1·096	1·148	20·1	79·9
35	1·110	1·166	20·5	79·5
40	1·122	1·179	21·0	79·0

TABLE SHOWING THE SOLUBILITY OF SALTS IN SUGAR SOLUTIONS.

(Jacobsthal.)

Solution containing	5% Sugar.	10% Sugar.	15% Sugar.	20% Sugar.	25% Sugar.
	Grams.	Grams.	Grams.	Grams.	Grams.
Calcium sulphate	2·095	1·946	1·593	1·539	1·333
,, carbonate	0·027	0·036	0·024	0·022	0·008
,, oxalate	0·033	0·047	0·012	0·008	0·001
,, phosphate	0·029	0·028	0·014	0·018	0·005
,, citrate	1·813	1·578	1·505	1·454	1·454
Magnes. carbonate	0·317	0·199	0·194	0·213	0·284

ADDITIONAL NOTES RELATING TO CERTAIN PORTIONS
OF THE TEXT.

Page 25.

Loethers Cane.—Mr. Prinsen Geerligs has informed the author that, at the outbreak of 'sereh' in Java the late Dr. Soltwedel introduced canes from all parts of the world in the search for an immune variety; among those from Mauritius was one, the label attached to which was read 'Loethers,' and afterwards it was surmised that 'Loethers' was a misreading for 'Louzier,' and in the Java literature the expression 'Loethers (Louzier)' frequently occurs. Now the cane illustrated by Soltwedel as Loethers bears no resemblance to the Louzier of Mauritius, the Bourbon of Demerara, the Lahaina of Hawaii, or the Otaheite of Cuba, whereas in all these four districts its characteristics are maintained unaltered. In addition, M. Auguste de Vilelle, to whom the author showed the drawing of Loethers in Soltwedel's portfolio of canes, at once recognized the cane as the 'Tamarind' of Mauritius. Admitting that canes may change their appearance widely under different climatological and soil conditions, the author is yet inclined to believe that the canes as sent must have been mislabelled. The Otaheite cane still remains of so great a value that a knowledge of its identity in all sugar districts is of great importance.

With regard to the Tibboo teelor cane mentioned on page 29, Mr. Geerligs states that 'teelor = egg' refers to the appearance of the flower, which in this cane does not develop, but remains a thick mass, resembling a cauliflower; it is eaten, cooked or pickled by the natives.

Page 32.

Tip Canes.—The striped and yellow tip canes are very similar to those known in Mauritius as *branchu rayée* and *branchu blanche*.

Page 32.

Uba Cane.—It was not until this book was in the press that the author had an opportunity of examining a specimen of this cane. It is a greenish cane, of slender habit, the diameter of the internodes being about $\frac{3}{4}$ inch. The internodes, averaging 6 inches, are very long in proportion to girth. The proportion of rind tissue is high, and a well-marked fistula occurs in the centre of the stalk. The nodes are swollen and the eyes are prominent; superficially, the dissimilarity from the Otaheite type of cane is so great as to suggest that on examination a systematist would separate this cane from the species *Saccharum officinarum.* A very good idea of the appearance of this cane can be obtained on inspecting the illustration of *S. glonggong* in Soltwedel's *Formen und Farben S. officinarum.*

Page 83.

Green Manuring.—It should be mentioned that some plants other than the leguminosae have bacterial nodules associated with their roots; it is not known yet whether these plants will have any value as green soilers, and for the present it is the leguminosae alone which need be considered.

Page 87.

Demerara Soils.—Reference may be made to two able articles on this subject appearing in *The International Sugar Journal*, April and May, 1910.

Page 138.

Fungus Diseases.—A very large number of fungi associated with the cane in South America have been described by Spegazzini in the *Revista Agricola y Veterinaria*, La Plata, and in other Latin-American journals. The author has never had access to these publications.

Page 148.

Thielaviopsis ethaceticus.—According to Patterson, Charles and Veihmeyer *(Bull. 171, Bureau of Plant Industry, U.S.D.A.)* this fungus was first described by De Seynes in 1886, as *Sporoschisma paradoxum;* in 1892, Saccardo renamed it *Chalara paradoxa;* it was in 1893 that Went described it as *Thielaviopsis ethaceticus*, and in 1904 Höhnel recognized the identity of the fungus. Hence, following the usually accepted system of nomenclature this fungus should be referred to as *Thielaviopsis paradoxa*. This organism is also the cause of dangerous rots of the pine-apple. The name ' Pine-apple disease,' attached to its manifestations on the sugar cane, is purely fortuitous, and is not connected with its faculty of attacking pine-apples.

Page 359.

Pan Control. - The electrical *recording* thermometers mentioned on page 424, as a means of controlling the combustion in the furnace, would form an ideal means of controlling the temperature in and during the whole operation of pan boiling ; such apparatus is already in use in the not very dissimilar industry of jam boiling.

Page 454.

Invertase.—The action of invertase extracted from yeast has very recently been studied in great detail by C. S. Hudson.—See *Jour. Indus. and App. Chem.*, Vol. II., page 143, and also a series of articles in the *Jour. Am. Chem. Soc.*, during 1909 and 1910.

Page 475.

Fibre.—The determination of fibre in sugar house control has special significance, and includes everything which is not juice. As employed in factory work it must be carefully distinguished from ' crude fibre ' or ' digestible fibre ' of plant physiology and analysis. Forming as it does the basis of the control of mill work, a method simulating the action of mills should be followed ; the most convenient method the writer knows of is to finely divide the cane, place a sample in a linen bag and squeeze out as much juice as possible in a powerful press ; the bag is removed from the press, the cake of fibre opened out by rubbing without removing from the bag, soaked in *cold* water and again pressed. This operation is repeated until the expressed juice is free from soluble solids ; this will take not more than six pressings, after which the residue, consisting of ' fibre,' is dried and weighed. In the absence of a press, washing of the finely divided sample in running *cold* water should be adopted.

INDEX.

Subject Matter.

Names.